Main Parameters of the Linac-Ring Type Phi, Charm and Tau Factories

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Parameters for linac-ring type $e^−e^+$ colliders with $\sqrt{s} = 1020$ MeV (φ factory), 3770 MeV (charm factory) and 4.2 GeV (τ factory) are discussed. It is shown that luminosities of the order of $10^{34}$ cm$^{-2}$s$^{-1}$ can be achieved.

I. INTRODUCTION

An old idea of colliding of the electron beam from a linac with a beam stored in a ring [1] is widely discussed during the last decade with two purposes: 1) to achieve the TeV energy scale in lepton-hadron and photon-hadron collisions (see review articles [2] and references therein), 2) to construct high luminosity particle factories, namely, B-factory [3], φ-factory [4,5], $c−\tau$-factory [6] etc.

Concerning the first direction, TESLA⊗HERA based $ep, γp, eA$ and $γA$ colliders are included in TESLA project [7]. And, Linac⊗LHC based $ep, γp, eA, γA$ and FELγA colliders [8] can be considered as the next step. On the other hand, linac-ring type B-factory lose its attractiveness with coming into operation of KEK-B [9] and PEP-B [10] colliders.

In this paper, we show that linac-ring type particle factories still is the matter of interest taking in mind φ, charm and τ options. In section 2, we present a general consideration of beam dynamics aspects of linac-ring type colliders. Proposed parameters for linac-ring type φ factory are given in section 3A where we also compare it with DAΦNE [11]. Linac-ring type charm and τ factories are discussed in sections 3B and 3C respectively. In the final section, we give some concluding remarks.

II. GENERAL CONSIDERATIONS

From the point of view of particle physics there are two most important collider parameters: center of mass energy and luminosity. For ultra-relativistic colliding beams, center of mass energy is given by

$$\sqrt{s} = 2\sqrt{E_1E_2}$$

(1)

In our case, $E_1$ is the energy of electrons accelerated in linac and $E_2$ is the energy of positrons stored in ring. For φ and charm factories, it is important to have $\Delta(\sqrt{s}) < \Gamma$ in order to use the advantage of resonant production of φ and $ψ(3S)$ mesons: $m_φ = 1019.417 ± 0.014$ MeV with $\Gamma_φ = 4.458 ± 0.032$ MeV and $m_ψ(3S) = 3769.9 ± 2.5$ MeV with $\Gamma_ψ(3S) = 23.6 ± 2.7$ MeV [12]. This condition is not so crucial for τ factory because of pair production of τ leptons.

The luminosity of $e^-e^+$ collisions is given by

$$L = \frac{N_eN_p}{2\pi\sqrt{(\sigma_{xe}^2 + \sigma_{xp}^2)(\sigma_{ye}^2 + \sigma_{yp}^2)}}f_cH_D$$

(2)

where $N_e$ is number of electrons per bunch, $N_p$ is number of positrons per bunch, $\sigma_{x,y}$ are horizontal and vertical beam sizes, $f_c$ is collision frequency. $H_D$ is luminosity enhancement factor which is calculated by using GUINEA-PIG beam-beam simulation program [13].
The first restrictive limitation for electron beam is beam power

\[ P_e = N_e E_e f_c \]  

which determines the maximum value of \( N_e f_c \) in Eq. (2).

The maximum number of electrons per bunch is determined by the beam-beam tune shift limit of the positron beam

\[ \Delta Q_p = \frac{N_e r_0}{2\pi \gamma_p} \frac{\beta_p^*}{\sigma_{xe}(\sigma_{xe} + \sigma_{ye})} \]  

where \( r_0 = 2.81 \times 10^{-15} \) m is the classical radius of the electron, \( \gamma_p \) is the Lorentz factor of the positron beam and \( \beta_p^* \) is beta function at collision point. Generally accepted beam-beam tune shift value for positrons in case of ring-ring colliders is \( \Delta Q \leq 0.06 \). This limit value can be a little bit larger for linac-ring type colliders.

Parameters of positron beams are constrained by the disruption \( D \) of electrons which is defined as the ratio of the positron bunch length to the electron focal length

\[ D_{ye} = \frac{\sigma_{zp}}{f_{ye}} = \frac{2 r_0 N_p \sigma_{zp}}{\gamma_e \sigma_{yd}(\sigma_{xp} + \sigma_{yp})} \]  

where \( \gamma_e \) is the Lorentz factor of the electron beam and \( \sigma_{zp} \) is the positron bunch length. In this study we consider the round beam case: \( \sigma_{ze} = \sigma_{ye} = \sigma_e \) and \( \sigma_{zp} = \sigma_{yp} = \sigma_p \). The analysis performed for linear colliders shows that \( D_{xe} = D_{ye} = D = 25 \) is acceptable [14].

## III. PARAMETER SETS

### A. Linac-Ring Type \( \Phi \) Factory

In order to make the linac-ring type \( \Phi \) factory feasible, its luminosity should exceed the luminosity of DAΦNE (operating standard ring-ring type \( \Phi \) factory at Frascati) at least by one order. The design luminosity of DAΦNE is \( 5.3 \times 10^{32} \) cm\(^{-2}\)s\(^{-1}\), however only \( L = 1.8 \times 10^{31} \) cm\(^{-2}\)s\(^{-1}\) has been achieved since start in 1999 [11]. Therefore, \( L = 5 \times 10^{33} \) cm\(^{-2}\)s\(^{-1}\) for linac-ring type machine will be quite enough, even if the design luminosity value would be achieved in DAΦNE. In Table I, we present proposed parameters for a number of linac-ring type \( \Phi \) factory options.

As mentioned in section II, in the case of \( \Phi \) and charm factories, it is important to obey condition \( \Delta(\sqrt{s}) < \Gamma \). The expected luminosity spectrum \( dL/dW \) for option C in Table I is plotted in Figure 1. We have used GUINEA-PIG simulation program [13] with \( \Delta E_{e^+}/E_{e^+} = \Delta E_{e^-}/E_{e^-} = 10^{-3} \). One can see that center of mass energy spread is well below \( \Gamma_\Phi \approx 4.46 \) MeV. Therefore, we can use the well known Breit-Wigner formula

\[ \sigma_{BW} = \frac{12\pi}{m_\Phi^2} B_{in} B_{out} \]  

where \( B_{in} \) and \( B_{out} \) are the branching fractions of the resonance into the entrance and exit channels. Branching fractions for different decay modes of the \( \Phi \) meson [12] are given in Table II. According to Eq. (6) we expect about \( 4 \times 10^{11} \) events per working year \( (10^7 \) s\). Number of events for different decay modes are presented in the last column of Table II.

### B. Linac-Ring Type Charm Factory

Recently CLEO-c (see [15] and references therein) proposal has been approved in order to explore the charm sector starting early 2003. With a necessary upgrade, expected machine performance for CLEO-c will be \( 3 \times 10^{32} \) cm\(^{-2}\)s\(^{-1}\) at \( \sqrt{s} = 3.77 \) GeV. In Table III, we present proposed parameters for three different linac-ring type charm factory
options. As one can see, \( L = 10^{34} \text{cm}^{-2}\text{s}^{-1} \) can be achieved which exceeds the CLEO-c design luminosity by more than an order.

In Figure 2, we plot expected luminosity spectrum for option C from Table III. It is seen that center of mass energy spread is well below \( \Gamma_{\psi(3S)} \approx 24 \text{MeV} \). Using the Eq. (6) with replacement of \( m_\phi \) to \( m_{\psi(3S)} \) and \( \text{Br}(\psi(3S \rightarrow e^+e^-)) \approx 10^{-4} \), we obtain the expected number of \( \psi(3S) \) per working year, which is about \( 10^{10} \). Let us mentioned that \( D \bar{D} \) mode is the dominant one for \( \psi(3S) \) decays. An additional advantage of the proposed charm factory is the asymmetric kinematics. This feature will be important in investigations of \( D^0\bar{D}^0 \) oscillations and CP-violations in charmed particle decays.

C. Linac-Ring Type \( \tau \) Factory

The cross section of the process \( e^+e^- \rightarrow \tau^+\tau^- \) for \( s << m_\tau^2 \) is given by

\[
\sigma = \frac{2\pi \alpha^2}{3s} \beta(3 - \beta^2) \approx \frac{43.4 \text{ nb}}{s \text{ (GeV)}^2} \beta(3 - \beta^2)
\]

where \( \beta = \sqrt{1 - 4m_\tau^2/s} \) and \( \alpha \) is the fine structure constant. The maximum value of \( \sigma = 3.56 \text{ nb} \) is achieved at \( \sqrt{s} \approx 4.2 \text{ GeV} \). In difference from \( \phi \) and charm factories, in the case of \( \tau \)-factory we have consider the symmetric option (\( E_{e^-} = E_{e^+} = 2.1 \text{ GeV} \)). Proposed set of parameters is given in Table IV. One can see that linac-ring type \( \tau \)-factory will produce \( \sim 4.6 \cdot 10^8 \tau^+\tau^- \) pair per working year, which exceeds by two order the statistics obtained at LEP and CLEO up to now.

IV. CONCLUSION

We have shown that linac-ring type machines will give an opportunity to achieve \( L = 10^{34} \text{ cm}^{-2}\text{s}^{-1} \), which essentially exceeds the luminosity values of existing and proposed standard (ring-ring type) \( \phi \), charm and \( \tau \) factories. This leads to an obvious advantage in search for rare decays. Another important feature of linac-ring type \( \phi \) and charm factories is the asymmetric kinematics. This will be important in investigation of oscillations and CP-violation in strange and charm sector of the SM.

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### TABLE I. Main parameters of φ factory

|                  | Option A | Option B | Option C |
|------------------|----------|----------|----------|
| $E_e$ (GeV)      | 0.130    | 0.130    | 0.260    |
| $E_p$ (GeV)      | 2        | 2        | 1        |
| $N_e$ ($10^{10}$) | 0.6      | 1        | 0.6      |
| $N_p$ ($10^{10}$) | 20       | 20       | 10       |
| $f_c$ (MHz)      | 30       | 30       | 30       |
| $\beta_e/\beta_p$ (cm) | 0.25/0.25 | 0.25/0.25 | 0.25/0.25 |
| $\sigma_N/\sigma_p$ (µm) | 3.77/9.44 | 4.95/9.44 | 5.33/4.65 |
| $\varepsilon_N/\varepsilon_p$ (µmrad) | 1.45/140 | 2.5/140 | 5.8/17 |
| $\Delta Q$      | 0.06     | 0.06     | 0.06     |
| $D$              | 24.77    | 24.77    | 25.5     |
| $H_D$            | 1.05     | 1.17     | 1.8      |
| $L$ ($10^{34}$ cm$^{-2}$s$^{-1}$) | 0.6      | 1        | 1.1      |
| Linac beam power (MW) | 3.74     | 6.24     | 7.48     |

### TABLE II. Rates of φ decays at linac-ring type φ factory

| Decay modes | Branching ratios | $N_{ev}$/year |
|-------------|------------------|---------------|
| $K^+K^-$    | 0.492            | 1.968·10$^{11}$ |
| $K^0_SK^0_S$| 0.338            | 1.352·10$^{11}$ |
| $\rho\pi$  | 0.155            | 0.620·10$^{11}$ |
| $\eta\gamma$ | 1.3·10$^{-2}$    | 5.200·10$^{6}$ |
| $\pi^+\pi^-$| 1.26·10$^{-3}$   | 5.040·10$^{7}$ |
| $\rho^+\rho^-$| 2.9·10$^{-4}$   | 11.64·10$^{7}$ |
| $\mu^+\mu^-$| 3.7·10$^{-4}$   | 14.80·10$^{7}$ |
| $\eta\pi^0\gamma$ | 1.3·10$^{-4}$ | 5.200·10$^{5}$ |
| $\pi^0\pi^0$ | 7.5·10$^{-5}$ | 30·10$^{5}$ |
| $\eta(958)\gamma$ | 6.7·10$^{-5}$ | 26.8·10$^{6}$ |
| $\mu^+\mu^-\gamma$ | 1.4·10$^{-5}$ | 5.6·10$^{6}$ |

### TABLE III. Main parameters of charm factory

|                  | Option A | Option B | Option C |
|------------------|----------|----------|----------|
| $E_e$ (GeV)      | 1        | 1.18     | 1.42     |
| $E_p$ (GeV)      | 3.55     | 3        | 2.5      |
| $N_e$ ($10^{10}$) | 0.1      | 0.1      | 0.1      |
| $N_p$ ($10^{10}$) | 10       | 10       | 10       |
| $f_c$ (MHz)      | 30       | 30       | 30       |
| $\beta_e/\beta_p$ (cm) | 0.25/0.25 | 0.25/0.25 | 0.25/0.25 |
| $\sigma_N/\sigma_p$ (µm) | 1.18/2.38 | 1.27/2.21 | 1.38/2.02 |
| $\varepsilon_N/\varepsilon_p$ (µmrad) | 1.1/15.8 | 1.5/11.5 | 2.15/8 |
| $\sigma_{ze}/\sigma_{zp}$ (cm) | 0.1/0.1 | 0.1/0.1 | 0.1/0.1 |
| $\Delta Q$      | 0.057    | 0.058    | 0.059    |
| $D$              | 25.34    | 24.82    | 24.78    |
| $H_D$            | 1.24     | 1.38     | 1.49     |
| $L$ ($10^{34}$ cm$^{-2}$s$^{-1}$) | 0.84     | 1        | 1.25     |
| Linac beam power (MW) | 4.8      | 5.66     | 6.8      |
TABLE IV. Main parameters of \( \tau \) factory

| Parameter          | Value       |
|--------------------|-------------|
| \( E_e \) (GeV)    | 2.1         |
| \( E_p \) (GeV)    | 2.1         |
| \( N_e \) \( \times 10^{10} \) | 0.07       |
| \( N_p \) \( \times 10^{10} \) | 10         |
| \( f_e \) (MHz)    | 30          |
| \( \beta_e / \beta_p \) (cm) | 0.25/0.25 |
| \( \sigma_e / \sigma_p \) (\( \mu m \)) | 1.28/1.65 |
| \( \varepsilon_e / \varepsilon_p \) (\( \mu m \)raad) | 2.7/4.5 |
| \( \sigma_{xe} / \sigma_{zp} \) (cm) | 0.1/0.1 |
| \( \Delta Q \)     | 0.057       |
| D                  | 25          |
| \( H_D \)          | 1.69        |
| \( L \) \( (10^{34} \text{ cm}^{-2} \text{s}^{-1}) \) | 1.29 |
| Linac beam power (MW) | 7          |

FIG. 1. Luminosity spectrum for \( \phi \) factory (option C).

FIG. 2. Luminosity spectrum for charm factory (option C).
Fig. 1
Fig 2