Study of Asymmetric ϕ Factory Options*

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Abstract

We review the scientific motivation of the development of asymmetric ϕ factories and discuss the various options. We describe two specific options: (1) a high energy e^- linac colliding with a low energy e^+ storage ring, (2) a high energy e^- storage ring colliding with a low energy e^+ storage ring. A critical comparison of these options will be discussed.

1 INTRODUCTION

Flavor factories (e^+e^-) are now established as an important component of the experimental equipment required to study elementary particles in the future, with emphasis on the study of CP violation, search for CPT violation and the detailed measurement of the parameters of the CKM matrix. To date, only two types of flavor factories have been studied:

- Symmetric (ϕ and Charm-τ factories)
- Asymmetric (B-factories with a ratio of 3:1 for the high energy and low energy beams)

We believe there will be a need for very asymmetric flavor factories (VAFF) where the ratio of the beam energies may vary up to 20:1[1, 2]. An example of such a factory is the asymmetric ϕ factory, where the major innovation is to give the K_S^0 beam a Lorentz boost γ of a factor of 3:1.

Very asymmetric collisions could be useful for ϕ factories, Z^0 factories, and second generation B factories. To our knowledge, no systematic study of VAFF has been carried out to date. In this report we first discuss some of the scientific motivation for VAFF, including the collision kinematics. We then discuss the various types of colliders, especially with respect to resulting luminosity and beam-beam interaction dynamics.

2 KINEMATICS OF AN ASYMMETRIC ϕ FACTORY

The key goals of ϕ factories are:

1. measurement of $[\epsilon'/\epsilon] \sim 10^{-4}$
2. search for CP violation in other decays, such as $K_S^0 \to \gamma\gamma$

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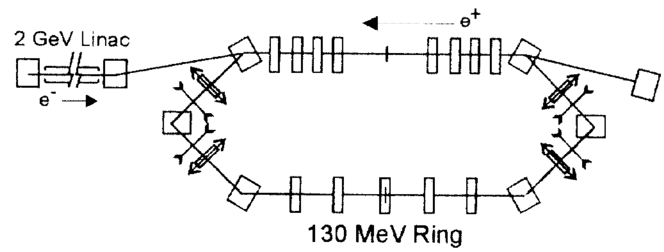

Figure 1: Possible layout of an asymmetric ϕ factory using a linac and a storage ring.

3. search for possible CPT violation at a very sensitive level
$$\left(\frac{M_{K^0} - M_{\bar{K}^0}}{M_K} < 10^{-18}\right)$$

All of the three goals require the study of K_S^0 mesons and a detector with extremely good resolution. All are documented in many studies at UCLA, Frascati, KEK, and Novosibirsk. We have previously proposed an asymmetric ϕ factory[1] to simplify these measurements and have also carried out extensive calculations for the proposed UCLA (Symmetric) Φ Factory[3]. In this note we compare the kinematics of symmetric and asymmetric ϕ factories and show how the experimental precision can be increased and the detector simplified for the latter case.

We consider the ϕ factory configuration shown in Figure 1, where a 2 GeV/c e^- linac beam collides with a stored 130 MeV/c e^+ beam. A scintillating fiber Pb detector covering the angular region of $\pm 60°$ is assumed for the purpose of reference. This will lead to a sharply reduced detector cost compared to that for a symmetric ϕ factory.

The major problem of studying K_S^0's at a symmetric ϕ factory is the very short decay length compared with the experimental resolution of final states, such as

$$K_S^0 \to \phi^0 \quad (1)$$
$$K_S^0 \to \gamma\gamma \quad (2)$$

Figure 2 shows the decay length distribution for symmetric and asymmetric collision energies. All new tests of quantum mechanics at ϕ factories require the insertion of some material into the beam in order to perform the measurement[4]. An asymmetric ϕ factory allows inserts

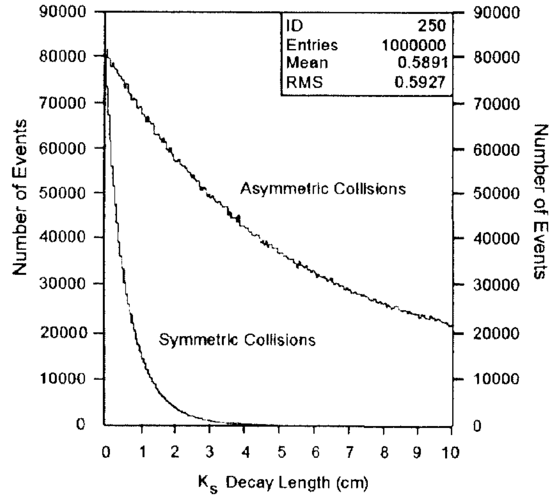

Figure 2: Decay length for the K_S particle for symmetric and asymmetric collision energies. In asymmetric case the particles are significantly boosted. Symmetric data uses the left ordinate, asymmetric data the right.

of 1-2cm of material and thus provides unique ways to test quantum mechanics.

3 VARIOUS ASYMMETRIC COLLIDER CONCEPTS

There are three generic collider designs for creating very asymmetric collisions between e^- and e^+ bunches with high luminosity. These are linac-on-ring, linac-on-linac, and ring-on-ring colliders. For this discussion we assume a high energy electron beam and a low energy positron beam. This is advantageous for the production of positrons. The details of each design type is quite involved. Here we wish to suggest some strengths and weaknesses of each, especially with regard to creation of high luminosities ($L \simeq 10^{33}\,\mathrm{cm}^{-2}\mathrm{sec}^{-1}$) at the mass of the ϕ ($E_{\mathrm{cm}} = 1020\,\mathrm{GeV}$).

3.1 Linac-on-Ring Option

The linac-on-ring option may be the most economical. New technologies make the 2 GeV linac seem reasonable, as would be a 0.13 GeV ring. The converse, beam collisions from a high energy e^+ ring on a lower energy e^- linac have been studied as an option for B-factories[5, 6]. Some work suggests an instability would develop in the ring beam from jitter in the linac beam, for the high energy ring case[7], which would also be a problem for the low-energy ring case.

For collisions in the low-energy ring the luminosity is limited by the beam-beam tune shift of the positron beam. Table 1 gives some parameters used to give an approximate luminosity of $10^{33}\,\mathrm{cm}^{-2}\mathrm{sec}^{-1}$. The variation of the longitudinal distribution during the collision, the bow-tie effect, for $\sigma_z \sim 1\,\mathrm{cm}$, decreases this to $0.2 \times 10^{33}\,\mathrm{cm}^{-2}\mathrm{sec}^{-1}$. The luminosity without this effect is given by

Table 1: Linac-on-ring ϕ factory parameters.

		E^+ Ring	E^- Ring
E	GeV	0.13	2
S_B	m	9	9
I	Amps	0.77	0.0018
ϵ_x, ϵ_y	nm	10, 2	1, 1
β_x^*, β_y^*	cm	0.65, 0.13	6.5, 0.26
ξ_x, ξ_y		0.05, 0.05	13.8, 2.78
$r = \sigma_y/\sigma_x$		0.2	
L_0	$\mathrm{cm}^{-2}\,\mathrm{sec}^{-1}$	10^{33}	
L	$\mathrm{cm}^{-2}\,\mathrm{sec}^{-1}$	0.2×10^{33}	

$$L_0 \;= 2.17 \times 10^{34}\,\xi^+\,(1+r)\left(EI/\beta_y^*\right)^{\pm}\ \mathrm{cm}^{-2}\mathrm{sec}^{-1} \quad (3)$$

where ξ is the beam-beam tune shift, r is σ_y/σ_x, E is the energy in GeV, I is the current in Amps, β_y^* is the vertical beta function at the interaction point in cm, and the beams sizes are transversely matched. To regain this lost factor, short bunches are desired such that σ_z/β_y^* is of the order unity. Using the smaller energy asymmetry of 10:1 and doubling β_y^* would decrease the bow-tie effect and increase the luminosity. Smaller bunch lengths might also be possible in the ring using strong RF and/or a lower momentum compaction factor.

The parameters in Table 1 push the state of the art in several places. The emittances for the e^+ bunch in the ring are small for such a high current, low energy beam. Also, the frequency with which the linac must deliver electrons to the interaction point is quite large. This could be achieved with many bunches in the linac for a single RF fill time, by using a superconducting linac. A microtron accelerator might also be used to deliver low current, small emittance bunches with a 9m spacing.

The linac-on-linac option, or linac-on-ring with collisions outside the ring, would avoid the above beam-beam tune shift limit on the positron beam. This allows the linac intensity to increase, however the lost collision frequency drastically decreases the luminosity. This assumes that the positrons are created and damped after each collision. Efficient, effective recirculation of the positron after collision would increase the collision frequency, increasing the luminosity.

3.2 Ring-on-Ring Option

The example we consider utilizes a superconducting 1.5 GeV electron ring and a conventional 180 MeV positron ring[8, 9]. A preliminary design has been made of a 23 meter circumference, 1.5 GeV ring, intended as a compact light source, which could be adapted to be the high energy ring, and the Brookhaven XLS ring, at 8.3 meters circumference and about 200 MeV, likewise might serve as the low energy ring[9]. Table 2 shows five beam-parameter sets roughly consistent with this combination.

Table 2:

		Case				
		1	2	3	4	5
Energy (GeV)	E^+	0.18	0.18	0.18	0.18	0.18
Energy (GeV)	E^-	1.5	1.5	1.5	1.5	1.5
Tuneshift	ξ	0.03	0.03	0.03	0.03	0.03
Bunch spacing (m)	S_B	10	10	10	10	10
Aspect ratio	r	0.04	0.04	0.04	1	1
Beam ratio	b	2	4	2	4	4
Current (mA)	I^+	180	360	402	360	720
Current (mA)	I^-	43	173	96	173	346
β^* values (cm)	β_y^+	2	4	4	8	1.6
	β_y^-	4	16	8	32	6.4
	β_x^+	50	100	100	8	1.6
	β_x^-	100	400	200	32	6.4
Emittances (nm)	ϵ_y^+	14.7	59	33	763	1526
	ϵ_y^-	7.3	15	16	191	382
	ϵ_x^+	367	1468	820	763	1526
	ϵ_x^-	183	367	410	191	382
Luminosity ($cm^{-2}s^{-1}$)	$\mathcal{L}$	10^{31}	10^{31}	10^{31}	10^{31}	10^{32}

These parameters use rules based on assumptions of equal beam sizes at the interaction point and equal tuneshifts[?]. These rules require specifying values of two free parameters, r and b:

$$r = (\beta_y/\beta_x)^* = \epsilon_y/\epsilon_x \quad \text{for } e^+ \text{ or } e^- \tag{4}$$

$$b = (\beta^-/\beta^+)^* = \epsilon^+/\epsilon^- \quad \text{for } x \text{ or } y \tag{5}$$

which lead to the luminosity expression:

$$\mathcal{L} = 2.17 \times 10^{34}\xi\,(1+r)\left(\frac{EI}{\beta_y}\right)^{\pm} \qquad (\mathrm{cm^{-2}sec^{-1}})$$

Besides choosing an appropriate set of beam parameters, one must address difficult problems such as designing of the interaction region or the injection system and finding a feasible method to replenish its positrons within the beam lifetime. These and other issues will be studied in the near future.

4 SUMMARY

We have discussed the design of two types of asymmetric ϕ factories (1) linac-on-ring or (2) ring-on-ring. During the next year we will carry out conceptual studies of both options to further compare these options.

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