On an Asymmetric Correlated Flavor Factory

 D. Cline, A. Boden, W. Gabella, A. Garren, X. Wang Center for Advanced Accelerators, Physics Department University of California Los Angeles
405 Hilgard Ave., Los Angeles, CA 90024

3. Search for possible CPT violation at a very sensitive level,

There are distinct physics advantages to using asymmetric ϕ factories to test and study CPT and CP violation. However, several beam dynamics issues remain to be addressed, especially for the effects of a high energy linac beam on a low energy target (most likely a storage ring or a recirculator structure). We present a preliminary discussion of collider concepts, especially with regard to the creation of high luminosities.

Abstract

I. 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) and 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 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 (3-10).

Very asymmetric collisions could be useful for ϕ Factories, Z^0 Factories, and 2nd 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 beambeam interaction dynamics.

II. KINEMATICS OF VAFF

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 $K_s^0 \rightarrow \gamma \gamma$;

$$\left(\frac{M_{K^0} - M_{\bar{K}^0}}{M_K} < 10^{-18}\right)$$

All of these goals require the study of K_S^0 mesons and a detector with extremely good resolution, and 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 Fig. 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 $\pm 60^{\circ}$ 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

$$K^0_s \rightarrow \pi^0 \pi^0 \quad , \qquad (1)$$

$$K^0_s \rightarrow \gamma \gamma$$
 . (2)

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

Another comparison concerns the energy distribution of the photons from reaction (1) above. We expect reaction (2) to give similar results. A symmetric ϕ factory has a very low energy tail on the photon distribution. It is difficult to detect photons with energy below 100 MeV and even more difficult those below 50 MeV with high efficiency. Also, the energy resolution improves as the photon energy increases. In Fig. 3(a) we compare the photon energy spectra for symmetric collisions. Fig. 3(b) shows the photon energy distribution for asymmetric collisions and for angles less than 60° with respect to the high energy beam direction. The combination of extended decay



Fig. 1. Possible layout of an asymmetric ϕ factory.



Fig. 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.

length and harder photon spectrum considerably increases the advantage of an asymmetric ϕ factory, and allows a relatively simple and inexpensive detector which we estimate will cost approximately 10% as much as the 4π detector proposed for the UCLA Symmetric ϕ Factory.

III. 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



Fig. 3(a). Distribution of photons from $K_0 \rightarrow \pi^0 \pi^0$ for the symmetric case. Photons accepted into the $\pm 60^\circ$ calorimeter are indicated in the shaded region.



Fig. 3(b). Distribution of photons from $K_0 \rightarrow \pi^0 \pi^0$ for an energy asymmetry of 20:1. Photons accepted into the $\pm 60^{\circ}$ calorimeter are indicated in the shaded region.

Table 1. Linac-on-Ring ϕ Factory Parameters			
	-	e ⁺ Ring	e ⁻ Linac
E	GeV	0.13	2
s _B	m	9	9
Ι	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	${\rm cm^{-2} \ s^{-1}}$	10 ³³	
L	$cm^{-2} s^{-1}$	0.2×10^{33}	

to suggest some strengths and weaknesses of each, especially with regards to creation of high luminosities ($L \approx 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$) at the mass of the ϕ ($E_{\text{cm}} = 1020 \text{ GeV}$).

The linac-on-ring option may be the most economical. New technologies make the 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} cm⁻² s⁻¹. The variation of the longitudinal distribution during the collision, the "bow-tie" effect, for $\sigma_z \sim 1$ cm, decreases this to 0.2×10^{33} cm⁻² s⁻¹. The luminosity without this effect is given by

$$L_0 = 2.17 \times 10^{34} \xi^+ (1+r) (EI/\beta_y^*)^+ \text{ cm}^{-2} \text{ s}^{-1} \quad , \quad (3)$$

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 given in cm, and the beams sizes are transversely matched. To regain this lost factor, short bunches are desired such that σ_z/β_i^* is of the order unity. Using the smaller energy asymmetry of 10:1 and doubling the 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 9 m 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 positrons after collision would increase the collision frequency increasing the luminosity.

For the ring-on-ring, the luminosity is reduced because the positron current must be lowered in order to keep the electron tune shift below 0.05. The positron current is limited to 0.0138 Amps giving a luminosity of $L \approx 2.6 \times 10^{31} \text{ cm}^{-2} \text{s}^{-1}$, where all the other parameters are the same as in Table 1.

We have not made an attempt to do more than discuss superficially the different options for a ϕ factory with an energy asymmetry of 20:1. However, the particle physics that can be accomplished at an asymmetric ϕ factory is compelling and complimentary to the program at the Frascatti symmetric ϕ Factory. No real conclusions can be made now about the best kind of collider to use, though it is clear that all the options presented above would need to push technological limits to reach the desired luminosity of 10^{33} cm⁻² s⁻¹.

REFERENCES

- [1] D. Cline, "A New Concept for an Asymmetric ϕ Factory to Test CPT and Study K_s^0 Mesons", in the *Proceedings of the XXVI International Conference on High Energy Physics*, Dallas, August, 1992; D. Cline, "Asymmetric ϕ Factories to Test CPT and Quantum Mechanics", to be published by World Scientific Press (1993).
- [2] Workshop on Asymmetric φ Factory Design, UCLA, October (1992); Workshop on Asymmetric Flavor Factory Design, UCLA, April (1993).
- [3] David S. Robin, Quasi-Isochronous Storage Ring Colliders: Energy Density Enhancement as a Route to High Luminosity, UCLA Ph. D. Thesis, UMI-92-15742-mc, 1991.
- [4] P. Eberhard and S. Chattopadhyay, "Asymmetric ϕ Factories—A Proposed Experiment and its Technical Feasibility", in *Proceedings of the 15th International* Conference on High Energy Accelerators, Hamburg, Germany, July, 1992.
- [5] P. Grosse-Weismann, "Colliding a Linear Electron Beam with a Storage Ring Beam", Nucl. Instrum. Methods, A274, 21 (1989).
- [6] B. Norum, "Studies of a Linac-Ring B-Factory", talk presented at Workshop on Asymmetric Flavor Factory Concepts, UCLA, April 2, 1993.
- [7] C. D. Johnson, "The Incoherent Beam-Beam Effect in Linear-on-Ring Colliders", in *Proceedings of the IEEE Particle Accelerator Conference*, San Francisco, California, May, 1991.