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A NEW CONCEPT FOR AN ASYMMETRIC Φ FACTORY TO TEST CPT AND STUDY K_S^0 MESONS*

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SEP 1992

Abstract

We propose a new type of e^+e^- collider with approximately co-linear beams that interact at small angles to produce energetic mesons and K_S^0 K_L^0 *beams*. We apply this concept to the collision of a 2 GeV e^- linear accelerator and a compact 1 GeV e^+ storage ring and show how high luminosity operation might be achieved as well as a crab crossing geometry. We discuss the experimental advantages of this scheme for producing energetic K_S^0 *beams* and $\phi \to K_S K_L$ interference compared to conventional ϕ factories.

1. INTRODUCTION

There is strong scientific justification for ϕ factories to study CP violation in the $K^0 \to \pi\pi$ system and to search for possible CPT violation. These rich scientific goals are documented in various workshop proceedings and in the proposals for the UCLA, Frascati, KEK and Novosibirsk ϕ Factories[1,2,3]. All of these proposals are designed for symmetric ϕ factories (i.e. equal e^+ and e^- energy)[4,5]. We now show the considerable advantages of an asymmetric ϕ factory.

There are problems with experiments at symmetric ϕ factories which are:

(1) The K_S^0 particles travel only ~ 6 mm on average.

(2) The K_S^0 decay at rest, thus the spectrum of photons, leptons and pions is rather soft (down to ~ 20 MeV).

(3) A 4π detector is required for a symmetric ϕ factory but a smaller detector is useful for an asymmetric ϕ factory.

In Fig. 1 we illustrate the effectiveness of an asymmetric ϕ factory for the case of 735 MeV e^- on 354 MeV e^+. In the cases studied here we assume a more asymmetric machine than for this case which improves the situation and reduces the detector size.

The study of $\phi \to K_S K_L$ decay provides an interferometer and the most important parameter being measured is the decay time distribution of the K_S in comparison with the K_L. Because of problems (1) and (2), precise measurements place great demands on the detector.

* Submitted for the proceedings of the XXVI International Conference on High Energy Physics held in Dallas, Texas, August 1992.

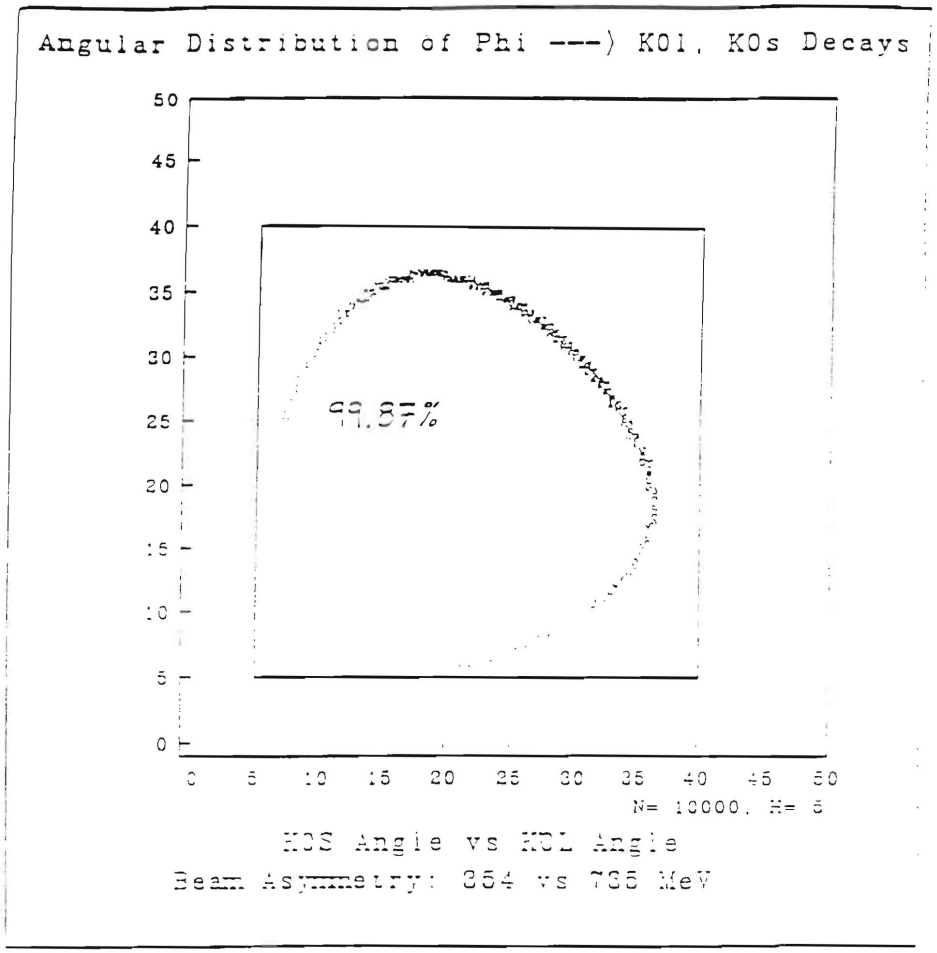

Fig. 1: From A. Boden, et al., A Linear Collider ϕ Factory and Beam Dynamics Test Machine. Published in the proceedings of the 1989 Blois Conference on CP Violation.

2. THE TEST OF CPT AT A ϕ FACTORY

These tests rely on precise measurement of K_S^0 decays and the ϵ_S parameter in the K_S^0, K_L^0 system. Any deviation from

$$\epsilon_S = \epsilon_L \tag{1}$$

would signal a breakdown. This could occur in the semi leptonic or non lepton channels. The ultimate problem of measuring ϵ_S at a symmetric ϕ factory is the level of systematic errors due to the very small decay length. An asymmetric ϕ factory, therefore, offers the potential of a superior measurement of ϵ_S and of CPT tests. Our goal is to test CPT, in a model independent fashion, tot he level of

$$\frac{M_{K^0} - M_{\bar{K}^0}}{\langle M_K \rangle} \leq 10^{-19} \tag{2}$$

which is in the same range as

$$\frac{M_{\text{quark}}}{M_{\text{Planck}}} \sim 10^{-18} - 10^{-19} \tag{3}$$

At this level it is quite possible that CPT could be violated.

3. THE ASYMMETRIC ϕ FACTORY

a) Method 1:

We consider two approximately colinear beams of e^+ and e^- with energies E_1 and E_2. The center of mass energy is given by

$$E_{cm} = \sqrt{2E_1E_2\,(1 - \beta_1\beta_2\cos\Theta)} \qquad (4)$$

where Θ is the angle between the beam (0^0 for colinear). In order to obtain a center of mass energy of the ϕ resonance and well below $\sqrt{2E_1E_2}$ we will require that the beam cross at a small angle such that $(1 - \beta_1\beta_2\cos\Theta)$ is small. The net momentum of the ϕ is given by $(\overline{P}_1 + \overline{P}_2)$. In the case we study here, we choose $E_1^{(e^-)}$ to be 2 GeV and $E_2^{(e^+)}$ to be 1 GeV. Thus, the net momentum of the ϕ is $\sim$ 3 GeV/c and the momenta of the K_S, K_L will be $\sim$ 1.5 GeV/c. The mean K_S decay length will be $\sim$ 2 cm and the K_S, K_L will be produced at an angle of $\sim 4°$. For $K_S \to \pi\pi$ the mean angle of the π's will be $\sim 16°$. The energy of the π^0 and γ from the decays will be similarly boosted. This will greatly simplify the detector for the ϕ physics. However, we note that the net ϕ energy should not be too great or the detector problems will again increase due to the small angles of the decay products.

The scheme proposed here is to collide a very intense low emittance e^- beam produced by a compact linac with a high current stored e^+ beam in a compact superconducting storage ring. This scheme is shown schematically in Fig. 2a. The beams are made to cross at the appropriate angle to produce the ϕ mass in the e^+e^- rest frame. To insure maximum overlap beam density and luminosity a crab crossing scheme may be useful. We also explore the possibility of increasing the interaction probability by having the e^+ and e^-

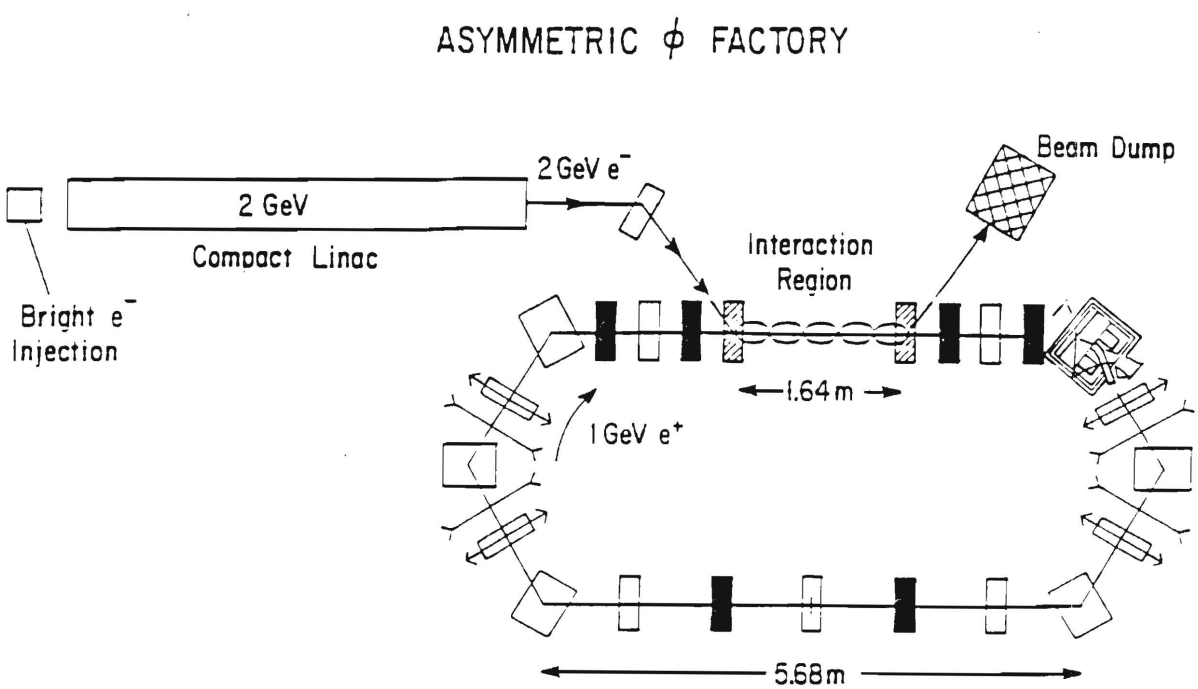

Fig. 2a: Schematic of an asymmetric ϕ factory that uses a linac and storage ring collider.

beams cross at several points in the interaction region in an oscillatory fashion. In principle, there could be many such beam crossings and the luminosity could be considerably enhanced.

The luminosity of the collider, assuming cross angles comparable to the physical crossing angles and large energy asymmetry, is given by

$$\mathcal{L} = \frac{f\, N_{e+}\, N_{e-}\, H}{4\,\pi\sigma_x\,\sigma_y}\,\ell \sin^2\theta \qquad (5)$$

where f is the interaction frequency, N_{e+} is the number of positrons in each bunch, N_{e-} is the number of electrons in each linac bunch, σ_x and σ_y are the transverse beam sizes, H is the pinch enhancement, and ℓ is the number of different interactions the beams make in the interaction area. We take the following parameters for illustration:

$$H = 1, \quad f = 2\times 10^4\,\mathrm{sec}^{-1}, \; N_{e+} = 2\times 10^{11},$$
$$N_{e-} = 5\times 10^{10}, \quad \sigma_x = \sigma_y = 10^{-4}\,\mathrm{cm},$$
$$\ell = 4, \quad \text{and} \quad \sin^2\theta = 1/4.$$

The resulting luminosity is

$$\mathcal{L} \simeq 1.6\times 10^{33}\,\mathrm{cm}^{-2}\mathrm{sec}^{-1} \qquad (6)$$

Note that these beams are not expected to be seriously disrupted due to the colinear nature of the collision. There will, however, be some electrostatic pinch for these colinear beams. We expect that the storage ring will need to be refilled every 4 – 5 hours under any extent. Since the revolution frequency of the storage ring is 14 MHz and the collision rate is 10^4 Hz, the positrons generally have 10^3 revolutions between collisions to partially damp out the effects of the interaction. Several bunch operations of the collider will also be envisioned.

The e^- linac should be a very compact device modeled on the the 1 GeV X-band test linac presently being constructed at SLAC. The e^- beam is driven by a bright RF gun/photocathode source. The e^+ storage ring is expected to follow the initial design of the UCLA Φ Factory storage ring with a modified lattice proposed by Al Garren and W. Gabella[6]. The storage ring will be 18 m in circumference. The positron source also follows the original UCLA Φ Factory design[4]. It is not clear, however, that full energy injection is required in the present case since it was originally proposed for the e^+e^- beam colliding in the same storage ring for the UCLA Φ Factory. It may be possible to accelerate in the storage ring to the desired energy and obtain the desired high current operation. These options will be studied in the forthcoming report.

b) Method 2:

A second method to produce an asymmetric ϕ factory is to achieve head on collision between the 2 GeV/c^2 e^- beam and a stored e^+ beam of energy 120 MeV/c^2. (In 1988 we studied a case for 735 MeV e^- on 354 MeV e^+ beams, A. Boden et al.) This case is illustrated in Fig. 2b. The positron storage ring can be constructed with normal magnets and the positron source can be generated using the spent e^- beam after the collision. The e^+ beam would have to be matched to the e^- beam in order to obtain the highest possible luminosity ($\sim 10^{33}\mathrm{cm}^{-2}\mathrm{sec}^{-1}$). The advantage of this scheme is that the storage ring is very modest and much less expensive. The disadvantage is the low energy beam dynamics. In the future a small team at UCLA will study this option. This concept is similar to the quasi linear collider scheme for $\bar{B}B$

Factories[7]. Another option to be studied is a 1 GeV e^- linac and a 250 MeV e^+ storage ring.

4. SUMMARY

In summary, we propose here a new type of ϕ factory that is asymmetric and helps overcome some of the most severe detector problems for the study of K_S^0's in a symmetric ϕ factory. We believe the detailed study of the $K_S^0 K_L^0$ interference patterns with the high time resolution that should be possible as the K_S^0 decays will provide a unique test of CPT and study of various CP violating amplitudes in the future.

In some ways this will be a second generation ϕ factory. This is due to the fact that, because the K_S^0, K_L^0, K^+, and K^- beams are now very collimated, it will be possible to carry out experiments with long decay paths as well without the need of an expensive 4π detector.

5. ACKNOWLEDGEMENTS

This report was written during my attendance at a meeting at the university of Washington, specifically the Institute for Nuclear Theory. I wish to take this opportunity to thank B. Holstein and W. Haxton for their hospitality during my visit.

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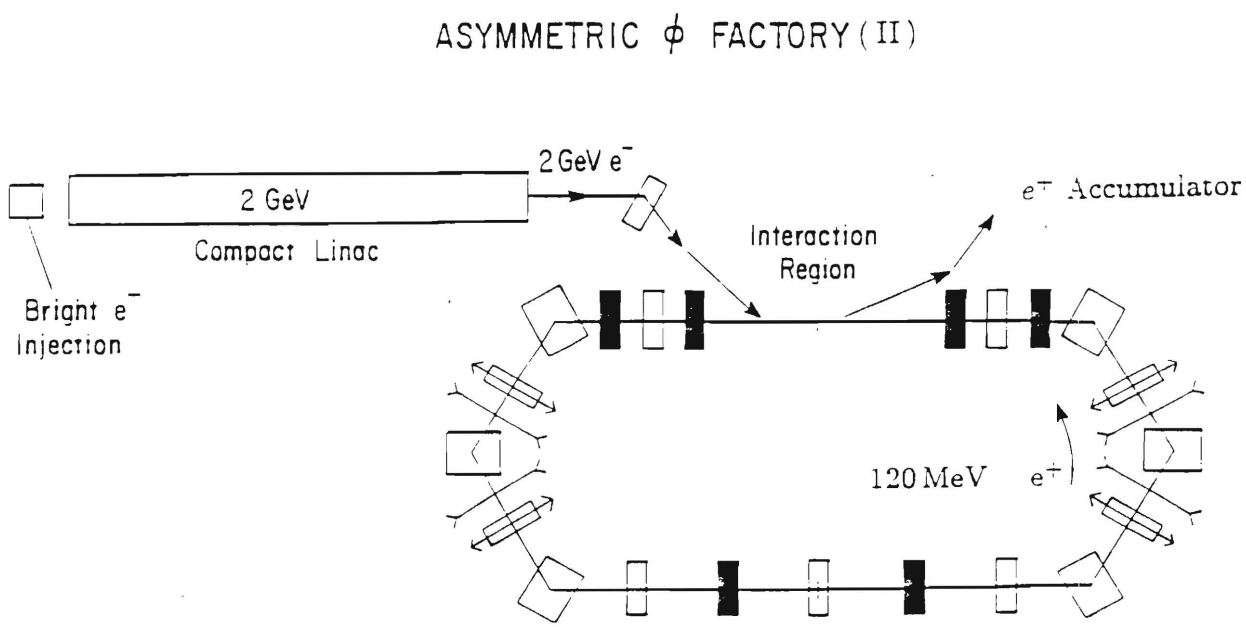

Fig. 2b: Schematic of an asymmetric ϕ factory using head on collisions between the e^+ and e^- beams.

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