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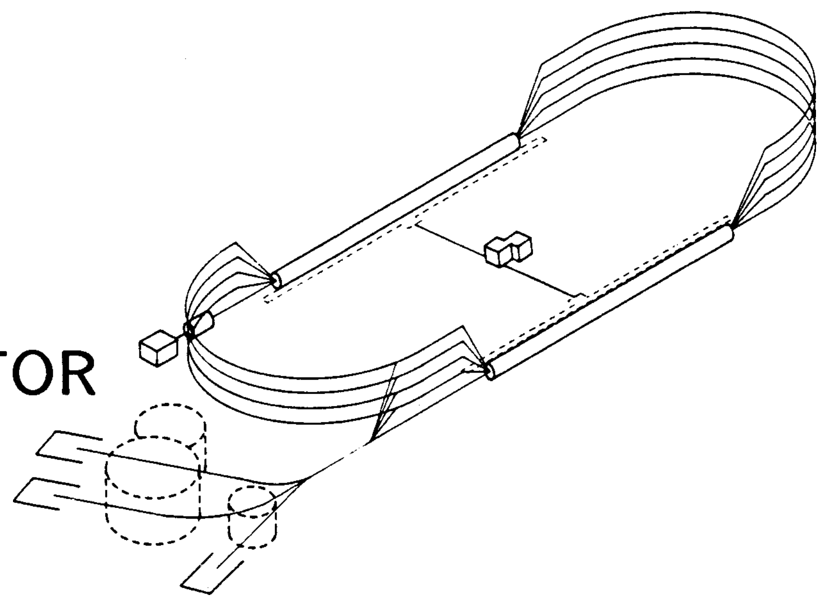

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A BEAUTY FACTORY USING AN SRF LINAC AND A STORAGE RING*

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Abstract

We present a brief review of accelerator facilities proposed for measuring CP violation in the B-meson system. In light of this comparison we discuss requirements for a B-factory using an e^+ storage ring beam colliding with a superconducting RF linac e^- beam to produce a luminosity of 10^{34} cm^{-2}sec^{-1}.

Introduction

Interest in B-physics has increased dramatically in recent years driven in part by the standard model prediction of large CP violation in the B-meson system and also in part by advances in accelerator physics.[1-4] One of the more promising methods whereby sufficient $B\overline{B}$'s are produced is by e^+e^- collisions at the $\Upsilon(4S)$ at $\approx$ 10 GeV. The fundamental challenge in this approach is to achieve beam conditions such that the luminosity at the interaction point (IP)

$$L = \frac{N_e N_p f_c}{4\pi\sigma_x\sigma_y} H_D \approx 10^{34}\ \mathrm{cm}^{-2}\ \mathrm{sec}^{-1} \qquad (1)$$

where:

$N_{e,p}$ = number of electrons or positrons
f_c = collision frequency
$\sigma_{x,y}$ = rms beam size at IP

and H_D is the "pinch enhancement factor,"[3] which we set to unity.

Most of the published B-factory designs concentrate on colliding e^+e^- beams both from storage rings or both from linacs.[5-10] It is clear from these studies that reaching a luminosity of 10^{33} cm^{-2}sec^{-1} is difficult and reaching 10^{34} cm^{-2}sec^{-1} is virtually impossible. The design with the highest value, the VLEPP design,[11] achieves $L = 7.5 \times 10^{33}$ cm^{-2}sec^{-1} . The question naturally arises: "Is there another way?"

Storage Ring on Linac

An interesting design has recently been proposed[12] whereby the positron beam is stored in a ring and collided with an electon beam from a linac. In this paper we investigate and expand this approach by careful examination of the beam current instability limitations of each machine along with the effect of the linac beam on the positron beam, i.e., the beam-beam tune shift. In particular these limitations are:

- collective instability effects in the ring itself: tune, Q_x; and impedance, $|\frac{Z_{\parallel}}{n}|$;
- small beam-beam tune shift value, $\xi \approx 0.06$, and
- realistic SRF linac specifications.[13]

The logic for our calculations is: first, specify ring parameters to maximize the positron beam; second, use $\xi = 0.06$ to find the maximum electron beam consistent with not disrupting the positron beam; and finally, vary the frequency, beam sizes, and energies, all consistent with the first two steps, to calculate L.

Storage Ring Limitations

The success of light source rings implies a current of 1 amp, though ambitious, is feasible. This, along with a collision frequency f_c, gives the number of positrons in a bunch, N_p.

Second, the critical impedance for single bunch microwave instability is given by:

$$|\frac{Z_{\parallel}}{n}| = \sqrt{\frac{\pi}{2}} Z_o \alpha\gamma\sigma_\delta{}^2\sigma_x / N_p r_e \qquad (2)$$

where $|\frac{Z_{\parallel}}{n}|$ is the effective longitudinal impedance, Z_o is the vacuum impedance (=377 Ω), γ is in units of m_oc^2, σ_δ is the bunch energy spread, σ_x is the bunch length, N_p is the number of positrons in the bunch, and r_e is the classical electron radius.

The experience of CESR[14] implies that at $\sigma_x \approx 1$ cm a $|\frac{Z_{\parallel}}{n}|$ value of 0.2 is achievable with care. Furthermore, since $\alpha \approx 1/Q_x{}^2$, the tune of the ring, Q_x, is determined.

Third, the condition for equilibrium emittance[3] in a ring is determined by:

$$\epsilon_x(\mathrm{m}) \approx 3.8 \times 10^{-13} \frac{\gamma^2}{Q_x^3}. \qquad (3)$$

With the addition of wigglers, this theoretical limit has been achieved in feasibility studies.

Beam-Beam Tune Shift Limitations

The beam-beam tune shift limit sets the number of electrons in the linac bunch by:

$$\xi = \frac{N_e r_e R^2}{2\pi\gamma\epsilon_x(R+1)}, \qquad (4)$$

where $R = \sigma_x/\sigma_y$ is the ratio of rms sizes at IP and $\sigma^2 = \epsilon\beta$ for the positron bunch. The beam-beam tuneshift, ξ, must be small; we have used a value of 0.06. More work is necessary on the beam dynamics of this storage ring/linac configuration to clarify parameter dependence.

SRF Linac Constraints

Collective effects in the linac must be considered. For N_e the emittance is limited by transverse wakefields. For normalized emittance of 10^{-6} and a frequency of 1500 MHz values of

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$N_e \approx 10^9$ and σ_δ on the order of 10^{-3} are reasonable. Multiple BBU effects limit the average current to about 20 mA. The bunch length for the CEBAF linac is on the order of 0.6 mm. This means that for an SRF linac the ratio of σ_z/β_z^* can be 2.

Power Considerations

A nontrivial consideration is the power budget required for such a B-factory. The power consumption for a linac is[12]

$$P(\text{MW}) = 0.16\ (N_e/10^9)\ (f_c/\text{MHz})\ (E_e/\text{GeV})/\eta_n \qquad (5)$$

where η_n is the efficiency which is 1.0 for an SRF linac.

The power for the storage ring is

$$P(\text{MW}) = 8.85 \times 10^{-2}\ (I/\text{Amps})\ (E/\text{GeV})^4/(\rho/\text{m}) \qquad (6)$$

and for this study we have taken $\rho = 80$ m.

Results and Discussion

Using the methodology outlined above we can arrive at a parameter list for a storage ring and linac B-factory:

Table 1 contains the parameter list for a 5-GeV on 5-GeV machine. The desired luminosity level is achieved; however, since the $B\overline{B}$'s are produced essentially at rest, the vertex resolution requirements for the detectors become exceedingly difficult.[3]

Table 2 contains parameters for a 10-GeV positron beam on a 2.5-GeV electron beam which, for an $E_{cm} = 10$ GeV, makes vertex resolution "do-able" though challenging. In this table, the aspect ratio R is varied from a round beam of R=1 to a very flat beam of R=100. The effect on luminosity is overshadowed by the dramatic effect on the power budget.

Table 3 shows the effect of varying f_c from 20 MHz to 10 MHz for the above asymmetric energy case with R=10. The effect on luminosity is negligible compared to the effect on required power.

Present SRF linac designs (e.g. CEBAF) must be modified to achieve the beam currents shown in Table 3. In particular, the installed power (a few MW) and the cryogenics design restrict N_e to $\approx 10^9$ particles per bunch, and thus the luminosity is reduced by a factor of 10. If the power is increased and (at a minimum) the HOM load is redirected to the exterior of the linac cryostats, then the desired luminosity levels could be achieved.

Conclusions

Achieving a luminosity of 10^{34} cm^{-2}sec^{-1} , as required to measure the size of CP violation in the B-meson system seems feasible with a storage ring beam colliding with an SRF linac beam. Further studies are required to optimize the machine configuration and to resolve whether there are important beam dynamics issues unique to this configuration.

Table 1
Equal Energies

Particle	e^-	e^+
$E_{particle}$ (GeV)	5	5
E_{cm} (GeV)	10.0	
f_c (MHz)	20.0	
N particles ($\times 10^9$)	1	262.
I (A)	3.2×10^{-3}	1
σ_x (μm)	5.7	5.7
σ_y (μm)	0.6	0.6
$R = \frac{\sigma_x}{\sigma_y}$	10	
σ_z (cm)	0.06	1.0
$\beta^*_{x,y}$ (cm)	0.5	0.5
ϵ_x (m)	6.6×10^{-9}	6.6×10^{-9}
Q_x	–	17.7
ξ	0.06	
Power (MW)	16.	.7
$\lvert\frac{Z_{\parallel}}{n}\rvert$ (Ω)	–	0.2
σ_δ	10^{-3}	1×10^{-3}
L (10^{34} cm^{-2} sec^{-1})	1.3	

Table 2
Aspect Ratio, $R = \frac{\sigma_x}{\sigma_y}$, Comparison

E_{cm} (GeV)	10			
f_c (MHz)	20			
I_p (A)	1			
ξ	.06			
Accelerator	SRF linac			Storage Ring
Particle	e^-			e^+
E_{particle} (GeV)	2.5			10
Q_x	–			23
ϵ_x (m)	–			1.2×10^{-8}
σ_z (cm)	0.06			1.0
β_x^* (cm)	0.5			0.5
σ_x (μm)	8			8
$R = \frac{\sigma_x}{\sigma_y}$	1	10	100	–
σ_y (μm)	8	0.8	0.08	$\sigma_{ye} = \sigma_{yp}$
N particles ($\times 10^9$)	64	3.5	0.32	312
I (A)	0.2	11×10^{-3}	1×10^{-3}	1
P (MW)	512	28	2.6	11
L (10^{34}cm^{-2}sec^{-2})	5.4	2.7	2.5	–

Table 3
Frequency Comparison
f_c = 20 MHz vs. 10 MHz

E_{cm} (GeV)	10			
ξ	0.06			
f_c (MHz)	20		10	
Particle	e^-	e^+	e^-	e^+
E_{particle} (GeV)	2.5	10.0	2.5	10.0
Q_x	–	23	–	16.2
ϵ_x (m)	–	1.2×10^{-8}	–	3.4×10^{-8}
σ_z (cm)	0.06	1.0	0.06	1.0
β_x^* (cm)	0.5	0.5	0.5	0.5
σ_x (μm)	8	8	13	13
σ_y (μm)	0.8	0.8	1.3	1.3
N particle ($\times 10^9$)	3.5	312	9.8	625
I (A)	11×10^{-3}	1	$16. \times 10^{-3}$	1
Power (MW)	28	11	39	11
L (10^{34} cm^{-2} sec^{-1})	2.7		2.9	

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