COMMENTS ON A LINAC BASED BEAUTY FACTORY

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ABSTRACT

A consistent set of parameters is given for a B-factory based on collisions of an electron beam from a SRF linac with the positron beam in a storage ring. An optimized lattice, an impedance estimate, a study of beam stability, and a discussion of collisions with large disruption parameters are included.

INTRODUCTION

Several recent workshops on B-factories (Cal Tech, Blois) clearly indicate that this problem has caught the interest of the high energy and accelerator communities. Preliminary estimates of the parameters of a SC linac based B-factory were presented at the Williamsburg conference in 1988¹. The B-factory design is based on the asymmetric collisions of an electron beam from the SC linac with the positron beam accelerated and stored in an independent storage ring (SR)². Here we give the results of a more detailed (but, of course, still incomplete) study of the feasibility and possible parameters of such a B-factory. As a model we use parameters of the CEBAF SC linac. The main goal is to achieve the luminosity $L \geq 10^{34} \text{ cm}^{-2} \text{ sec}^{-1}$ at a total energy equal to $m(\Upsilon) = 10.58 \text{ GeV}$. We will show that these criteria, together with the conditions of stability and some practical limitations (on the emittance, the SR impedance, the bunch spacing), basically define the whole set of B-factory parameters. The main problem in such an approach is the large disruption parameter of the electron bunches. We discuss and model such collisions to demonstrate that it is possible to preserve stability of the positrons under these conditions. The problem of obtaining high luminosity is very challenging, and all parameters of the machine marginally achievable. First we discuss the various constraints, and then choose a consistent set of machine parameters.

LINAC

The main advantages of a superconducting linac are the relatively low emittance of the electron beam compared to a storage ring, and the relatively low wall losses compared to a room temperature linac. Since a large aperture is allowed, the transverse impedance is reduced.

Having asymmetric collisions gives preferable kinematics for analysis of the CP violation in B decays and allows a low energy electron beam. We choose the energy of the electron beam to be 3.5 GeV. Lower electron energy increases the energy of the SR, the power consumption in the SR, and the emittance of the positron beam.

The main limitation on the electron current is given by the single bunch transverse beam break-up (BBU) instability. The multibunch instability gives a less severe constraint. The beam breakup code TDBBU³ has been used for numeric studies of the BBU instability. Fig. 1 shows the emittance degradation obtained for parabolic bunches with the density profile

Fig. 1. Emittance degradation in the linac.

$$\rho(z) = \frac{3N}{2l} \left[1 - \left(\frac{2z}{l} \right)^2 \right], \quad |z| < L/2, \quad l = 4.47 \sigma$$

with different full length l as a function of the peak current I_p . In the simulation the slope w of the transverse wake field is equal to $w = 30.0 \text{ V/pC/cm}^2$ per cavity, and the number of cavities is 1600. The emittance of the $l_e = 2.2 \text{ psec}$ bunch doubles with the peak current exceeding 571 A, or

$$w_{total} * I_p = 2.74 \cdot 10^7 \text{ A V/pC/cm}^2. \quad (1)$$

This corresponds to $N_e = 5.26 \cdot 10^9$ particles per bunch. For the same bunch length the emittance increases 4.8 times at $I_p = 1000 \text{ A}$. Hence, the luminosity which is proportional to the ratio I_p/ϵ_e decreases if I_p increases above the doubling threshold.

The doubling threshold rapidly decreases with the bunch length. For example, the normalized emittance doubles for a 4 psec full length bunch if $I_p * w_{total} > 5 \cdot 10^5 \text{ A V/pC/cm}^2$. Therefore, we choose a 2.2 psec bunch length of the electron beam for the B-factory.

The effective CEBAF impedance gives⁴ the slope $w = 94.22 \text{ kV/pC/cm}^2/\text{pass}$ or $290 \text{ V/pC/cm}^2/\text{cavity}$. Scaling the result of Eq. (1) to that slope, we get the doubling threshold $N_e = 5.44 \cdot 10^8$ for the final energy 4 GeV.

The estimate shows that the main degradation of the emittance occurs on the first pass. Hence, neglecting the weak dependence on energy we assume

$$N_e = 0.544 \cdot 10^9, \quad I_{av} = 1.6 \text{ mA}. \quad (2)$$

The dependence on the energy may be studied analytically by solving the equation of motion⁵. For the first pass at CEBAF the betatron wave length is kept constant: $k_0 = 2\pi/\lambda_\beta$, $\lambda_\beta = 56.4$ m. For the next passes $k^2(s) = k_0^2 (\gamma_1(s)/\gamma(s))$ where the index 1 refers to the first pass and s gives the location along the orbit. For small amplitude betatron oscillations the δ -functional transverse wakefield per unit length for the short bunches is defined by the slope W'' :

$$W(z, x, s) \simeq W''(s) x z$$

where z is the distance from the head of the bunch to the tail. The equation of motion takes the form:

$$\frac{d}{ds}(\gamma x') + k_0^2 \gamma_1(s) x = N_B r_0 W'' \int_z^\infty dz' \rho(z') (z' - z) x(z', s). \quad (3)$$

(The actual dependence on the distance between particles z , is, probably, $\sqrt{z}$. In this case W'' should be considered as the "effective" slope giving the correct wake at the end of a bunch). Here ρ is the normalized charge density.

The solution is obtained by iterations:

$$x = \frac{A}{\gamma(s)} \left\{ \cos \left(\int_0^s k ds \right) + \lambda \sin \left(\int_0^s k ds \right) + \dots \right\}$$

where

$$k^2(s) = k_0^2 \frac{\gamma_1(s)}{\gamma(s)} + \left(\frac{\gamma'}{2\gamma(s)} \right)^2.$$

The second term, proportional to the acceleration rate ($\gamma' = 5 \text{ m}^{-1}$), is small even for the first pass and can be neglected.

The first iteration could have been computed from the WKB approximation. Averaging the fast oscillating terms gives the enhancement factor λ at the tail of the bunch with the length l_B as

$$\lambda = \frac{\Lambda}{\sqrt{k(s)} \int_0^s \frac{ds' W''(s')}{\gamma(s') \sqrt{k(s')}}}, \quad \Lambda = \frac{N_B r_0 l_B}{2}. \quad (4)$$

Estimating λ for the first pass and introducing the total slope w we obtain

$$\lambda = \frac{\Lambda}{k_0 \gamma_{1f}} \left[w_{linac} \ln \frac{\gamma_{2f}}{\gamma_{1i}} + w_{arc} \left(1 + \frac{\gamma_{1f}}{\gamma_{2f}} \right) \right] \quad (5)$$

where indexes 1, 2 refer to the first and to the second linacs of the first pass, and i, f refer to the beginning and the end of the linacs. According to Eq. (4) the dependence on the final energy is weak: the main contribution may be expected from the first pass.

The total slope of the wake is the sum over all impedance generating elements of different types

$$w = \int ds W'' = \sum W_i n_i.$$

It has been estimated⁴ as

$$w_{linac} = 8.45 \cdot 10^3 \text{ cm}^{-3}$$

for a linac, and as

$$w_{arc} = 4.87 \cdot 10^4 \text{ cm}^{-3}$$

for an arc.

The threshold of instability corresponds to $\lambda \simeq 1$, giving $N_B = 0.2 \cdot 10^9$ in agreement with the numeric simulations.

One might attempt to increase the peak current by BNS phasing the linac⁶ to minimize the emittance degradation*. If the head of a bunch has the phase ϕ_0 behind the crest of the RF voltage in the cavities, then the energy of a particle depends on the distance z of the particle from the head of the bunch:

$$\gamma(s, z) = \gamma(s, 0) \left[1 - \frac{2\pi z}{\lambda_{RF}} \tan \phi_0 \right].$$

A dependence of $\gamma_1 k_0^2$ in Eq. (3) on z is generated which can compensate the part of the wake linearly dependent on z in the right hand side of the equation if

$$\tan \phi_0 = \frac{N_B \tau_0 W'' \lambda_{RF}}{4\pi \gamma(0, s) k_0^2}.$$

With this choice of the phase ϕ_0 the motion of following particles in the bunch is the same as the motion of the particle at the head of the bunch. However, for $N_B = 10^9$, $\lambda_{RF} = 20 \text{ cm}$, $w_{linac} = 16.9 \cdot 10^3 \text{ cm}^{-3}$, $\gamma = 10^3$, and for the length of the linac $L = 240 \text{ m}$, the phase $\phi_0 = 84.2^\circ$ would drastically reduce the acceleration rate making BNS phasing unacceptable.

The power in the beam in the linac is

$$P = 0.16 \left(\frac{N_e}{10^9} \right) \left(\frac{f}{\text{MHz}} \right) \left(\frac{E}{\text{GeV}} \right) \left[\frac{MW}{\eta} \right].$$

For a SC linac the efficiency $\eta \simeq 1$. This gives $P = 5.65 \text{ MW}$ for the repetition rate $f = 20 \text{ MHz}$ and $E_e = 3.25 \text{ GeV}$.

Power deposition in the cold section of the linac may be a limiting factor. For example, the loss factor estimated for CEBAF cavities⁴ is $k_l = 9.15 \text{ V/pC}$ for 2.2 psec bunches. Most of the loss comes from the high frequency modes (3.2 V/pC from the modes with frequency $f < 6.5 \text{ GHz}$). The losses in the fundamental power coupler and the HOMs increase this factor to 15 V/pC per cavity. The power deposition per cavity with N_e given by Eq. (5), and $f = 20 \text{ MHz}$ is

$$P = e^2 N_e^2 k_l f = 2.0 \text{ W/cavity}.$$

For comparison, the CEBAF cryounit can handle 5 W/cavity. The cryogenic load could be reduced by increasing the bunch length,

$$k_l \sim 1/\sqrt{\sigma_l}.$$

However, that would reduce luminosity.

* In the simulations⁵ the phasing minimized the energy spread.

STORAGE RING

At the $\Upsilon(4S)$ resonance ($M = 10.58$ GeV, $\Gamma(\Upsilon) = 24$ MeV) the energy of the positron beam E_p is related to E_e :

$$E_e E_p = 27.984 (\text{GeV})^2, \quad \hat{\gamma}_e \hat{\gamma}_p = 107.169. \quad (6)$$

Here and later we use for convenience $\hat{\gamma}$ defined as $\gamma = \hat{\gamma} 10^3$.

The optics of the SR has to be chosen to minimize the transverse emittance, allowing storage of large average current. The single mode longitudinal instability limits the average current in the SR:

$$\frac{I_{av}}{I_A} \leq \sqrt{\frac{\pi}{2}} \frac{Z_0}{s_B} \frac{\alpha \gamma_p \sigma_\delta^2 \sigma_{p,z}}{(\frac{Z}{n})_{eff}}$$

where $Z_0 = 377$ Ohm, $I_A = ec/r_0 = 1.7 \cdot 10^4$ A, s_B is the bunch spacing, and $(\frac{Z}{n})_{eff}$ is the effective impedance.

We can rewrite this as

$$\frac{I_{av}}{A} \leq 0.86 \cdot 10^{12} \frac{\alpha \sigma_\delta^2 \sigma_{p,z}}{s_B \hat{\gamma}_e (\frac{Z}{n})_{eff}} \text{ Ohm}. \quad (7)$$

As is clear from Eq. (7), I_{av} increases with the energy spread σ_δ , compaction factor α , and the bunch length $\sigma_{p,z}$. For example, $I_{av} = 0.5$ A can be obtained with $S_B = 15$ m, $\hat{\gamma}_e = 6$, $\sigma_{p,z} = 1$ mm, and $(\frac{Z}{n})_{eff} = 0.5$ Ohm if $\alpha \sigma_\delta^2 = 2.6 \cdot 10^{-8}$. However, large $\alpha \sigma_\delta^2$ requires high RF voltage, i.e. a large number of RF cavities. That increases the contribution of the cavities to the effective impedance. If this contribution becomes dominant I_{av} does not increase with $\alpha \sigma_\delta^2$ any further. We assume that the rest of the effective impedance (the contribution of the beam pipe discontinuities) could be as low as

$$\left(\frac{Z}{n}\right)_{lattice}^{eff} = 0.25 \text{ Ohm} \quad (8)$$

and use that for the comparison with the total impedance of the RF cavities.

We discuss first the choice of the lattice for the SR, and then give the estimate of the impedance of the cavities.

LATTICE

The equilibrium horizontal emittance ϵ_x , energy spread σ_δ , and the compaction factor α are given⁷ for decoupled x and y motion in terms of the horizontal dispersion function D_x and the β_x function:

$$\epsilon_x = \frac{\lambda_0}{J_x} \frac{\langle K^3 f(s) \rangle}{\langle K^2 \rangle}$$

$$\sigma_\delta^2 = \frac{\lambda_0}{J_z} \frac{\langle K^3 \rangle}{\langle K^2 \rangle}$$

$$\alpha = \langle K D_x \rangle.$$

Here $K = 1/\rho$ is the curvature in the bend magnets,

$$\lambda_0 = \frac{55\sqrt{3}}{48} \Lambda_c \gamma^2 = 3.06 \cdot 10^{-6} (E/\text{GeV})^2,$$

J_x, J_z are the partition functions:

$$J_x = \frac{1}{\langle K^2 \rangle} \langle K^2 [1 - (1 - 2n) K D_x] \rangle, \quad J_z + J_x = 3,$$

and

$$f(s) = \frac{1}{\beta_x(s)} \left[D_x^2 + \left(\beta_x D'_x - \frac{1}{2} \beta'_x D \right)^2 \right].$$

For a periodic structure with the cell length L and the phase advance per cell $\mu_c = 2\pi\nu$,

$$D_x(s) = \frac{\sqrt{\beta_x(s)}}{2 \sin(\pi\nu)} e^{i(\mu(s) + \pi\nu)} \int_s^{s+L} ds' B(s') + \text{c.c.}$$

where

$$B(s) = K(s) \sqrt{\beta_x(s)} e^{-i\mu(s)}.$$

The function $f(s)$ takes the form

$$f(s) = \frac{1}{4 \sin^2(\pi\nu)} \left| \int_s^{s+L} ds' B(s') \right|^2.$$

The function $B(s) \neq 0$ only in the bend magnets. For short dipoles, and taking into account that $\beta_x \propto L$ we obtain the well known scaling:

$$\alpha \propto \theta_c^2, \quad \sigma_\delta^2 \propto \frac{\lambda_0 \theta_c}{J_z L}, \quad \epsilon_x \propto \frac{\lambda_0 \theta_c^3}{4 J_x}.$$

Here we used the bend angle of the cell $\theta_c = KL$.

Notice, that the emittance and $\alpha\sigma_\delta^2$ are related:

$$\epsilon_x = \left(\frac{J_z}{J_x} \right) \alpha \sigma_\delta^2 L \Phi(\nu)$$

where $\Phi(\nu) \simeq 1$ depends on the details of the cell structure.

The B-factory lattice has to be designed to minimize the emittance with relatively large $\alpha\sigma_\delta^2$. Emittance depends basically on the bend angle. Small emittance requires short bends. Given emittance, $\alpha\sigma_\delta^2$ can be increased reducing the cell length L . Additional reduction of the emittance with simultaneous increase of $\alpha\sigma_\delta^2$ can be obtained by reducing J_x . This requires combined function dipoles focusing in the horizontal plane.

We choose a short cell with combined function dipoles focusing in the x -plane and a defocusing quad. We do not use more sophisticated lattices because they require longer cells. To get enough flexibility, the dipole is split into two halves with a thin

focusing quadrupole between them. That makes the cell similar to the usual FODO structure. We give as an example the results for the two model cells:

$$L = 5 \text{ m}, 2L_b = 4.0, L_{q,D} = 0.40 \text{ m}, L_{q,F} = 0.20 \text{ m}, \rho = 45.0 \text{ m}$$

$$K1_{q,D} = 2.0 \text{ m}^{-2}, K1_{q,F} = -1.8 \text{ m}^{-2}, K1_b = -0.12 \text{ m}^{-2}.$$

This gives at the energy 7.94 GeV

$$\nu_x = 0.283, \nu_y = 0.255, \beta_x = 9.8 \text{ m}, \beta_y = 1.4 \text{ m}, D_x = 0.255 \text{ m}, J_x = 2.65, J_z = 0.344,$$

$$\alpha = 0.273 \cdot 10^{-2}, \sigma_\delta = 0.244 \cdot 10^{-2}, \epsilon_x = 6.18 \cdot 10^{-9} \text{ m}, \Delta E = 0.110 \text{ MeV/cell},$$

$$\tau_x = 0.9 \text{ msec}, \tau_y = 2.4 \text{ msec}, \tau_E = 6.9 \text{ msec}.$$

The lattice is flexible: using $\rho = 43 \text{ m}$, and $K1_b = -0.06 \text{ m}^{-2}$ we obtained $\alpha = 0.208 \cdot 10^{-2}$, $\sigma_\delta = 0.124 \cdot 10^{-2}$, $\epsilon_x = 7.45 \cdot 10^{-9} \text{ m}$ at $E = 8.02 \text{ GeV}$.

IMPEDANCE

Let us now estimate the impedance of the RF cavities. We start with the impedance of a single cavity. A high frequency RF system minimizes the RF voltage needed for short bunches. To minimize impedance and the losses we choose for our studies SC CEBAF 1.5 GHz cavities. In the modal analysis the impedance is

$$Z(\omega) = i \sum_n \chi_n (\omega - \omega_n + i\gamma_n)^{-1}$$

where the loss factors

$$\chi_n = \frac{L\omega_n}{2} \left(\frac{r}{Q} \right)_n$$

depend on the length of the structure L and the (r/Q) for each mode as they are given by URMEL (in units Ohm/m). Hence, the loss is

$$\text{Re} \int^\omega d\omega Z(\omega) = \frac{\pi L}{2} \sum_{\omega_n < \omega} \omega_n \left(\frac{r}{Q} \right)_n.$$

The sum has been calculated for CEBAF cavities ($L = 0.5 \text{ m}$) for the modes given by URMEL⁸ with frequencies up to 6 GHz. The sum behaves as $\sqrt{k}$, $k = \omega/c$:

$$\sum_{\omega_n < \omega} \frac{\omega_n}{2\pi} \left(\frac{r}{Q} \right)_n = \Lambda \sqrt{k}$$

where $\Lambda = 2.67 \cdot 10^6 \text{ (Ohm/m) MHz } \sqrt{\text{cm}}$, as in Fig. 2. This means that the average $\text{Re } Z(\omega)$ is inversely proportional to $\sqrt{k}$:

$$\text{Re } Z(k) = A/\sqrt{k}, \quad A = \frac{\pi^2 L \Lambda}{2c} = 220 \text{ Ohm}/\sqrt{\text{cm}}.$$

Fig. 2. The sum $\sum_{f < f_{max}} f_n(r/Q)_n$ for CEBAF cavities vs. frequency f_{max} .

Let us compare this result with the estimated⁴ total loss $k_l = 17.5$ V/pC/cavity for a $t_b = 2.2$ psec bunch. For a Gaussian bunch with rms length σ

$$k_l = \int \frac{d\omega}{2\pi} Z_l(k) e^{-k^2 \sigma^2}.$$

Assuming $Z(k) = A/\sqrt{k}$ we obtain

$$k_l = 0.577 \frac{A c}{\sqrt{\sigma}}.$$

This gives 17.5 V/pC for $\sigma = 2.2$ psec $\cdot c/4 = 165 \mu\text{m}$ if $A = 130$ Ohm/ $\sqrt{\text{cm}}$, agreeing within a factor of 2 with the previous estimate.

For the following discussion we assume

$$Z(k) = A/\sqrt{k}, \quad A = 200 \text{ Ohm}/\sqrt{\text{cm}}. \quad (9)$$

The effective impedance is dominated by the lowest collective mode

$$\left(\frac{Z(n)}{n} \right)_{eff} = \frac{\int (Z/n) k^2 \sigma^2 e^{-k^2 \sigma^2} dk}{\int e^{-k^2 \sigma^2} dk}.$$

For the model Eq. (9) this gives

$$(Z/n)_{eff} = 1.5 \cdot 10^2 \frac{\sigma^{3/2}}{R} \text{ Ohm}/\sqrt{\text{cm}}/\text{cavity}.$$

The number of RF cavities in a storage mode is given by the losses per turn ΔE :

$$\Delta E = eV \cos \phi_s,$$

and the bunch length. The rms bunch length is related to the rms energy spread:

$$\sigma_z = \frac{\alpha R}{\nu_s} \sigma_\delta$$

where ν_s is the synchrotron tune

$$\nu_s = \sqrt{\frac{qeV \alpha \sin \phi_s}{2\pi E_p}}, \quad q = 2\pi R / \lambda_{RF}.$$

Assuming that $\Delta E \ll eV$ we obtain:

$$eV = \frac{\alpha \sigma_\delta^2 R \lambda_{RF}}{\sigma_z^2} E_p$$

Therefore, n_{cav} CEBAF-type cavities are required with the acceleration rate $E' = 2.5$ MeV/cavity with

$$n_{cav} = \frac{\alpha \sigma_\delta^2 \gamma_p R \lambda_{RF}}{5 \sigma_z^2}. \quad (10)$$

Notice, that the $\alpha \sigma_\delta^2 R$ depends on the bending angle of the dipoles but not on the cell length and is fixed for a given transverse emittance.

The total effective impedance of the cavities is

$$(Z/n)_{cav, eff} = 1.03 \cdot 10^7 \frac{\alpha \sigma_\delta^2 \lambda_{RF}}{\hat{\gamma}_e \sqrt{\sigma_z / \text{mm}}} \frac{\text{Ohm}}{\text{cm}}. \quad (11)$$

The maximum current given by Eq. (7) and Eq. (11) is

$$\left(\frac{I_{av}}{0.5 \text{ A}} \right) = 167.0 \kappa \frac{(\sigma_z / \text{mm})^{3/2}}{(s_B / \text{m})(\lambda_{RF} / \text{cm})} \quad (12)$$

where

$$\left(\frac{1}{\kappa} \right) = 1 + \frac{(\frac{Z}{n})_{latt}^{eff}}{(\frac{Z}{n})_{cav}^{eff}}. \quad (13)$$

The parameter $\kappa \simeq 1$ for large $\alpha \sigma_\delta^2$, and is equal to 0.5 if $(\frac{Z}{n})_{cav}^{eff} = (\frac{Z}{n})_{latt}^{eff}$.
The number of cavities is

$$n_{cav} = \frac{(\frac{Z}{n})_{latt}^{eff}}{\text{Ohm}} \left(\frac{\kappa}{1 - \kappa} \right) \frac{(R / \text{m})}{(\sigma_z / \text{mm})^{3/2}}.$$

For $(\frac{Z}{n})_{latt}^{eff} = 0.25 \text{ Ohm}$ this gives

$$n_{cav} = 5.2 \left(\frac{\kappa}{1 - \kappa} \right) \frac{(R / \text{m})}{(\sigma_z / \text{mm})^{3/2}}. \quad (14)$$

COLLISIONS BEAM DISRUPTION

One of the main phenomenon affecting the choice of the machine parameters is the disruption of the bunches during a collision. In the scheme under consideration the electron bunch is dumped after the collision. The disruption of the electron beam affects the kinematics of the collisions, creates a problem with the background in the detectors, and makes handling of the electron beam after collisions more difficult. However, the main problem is that the disrupted electron bunch affects the dynamics of the positrons generating orbit distortion and a tune shift. Different positrons see different cross-sections of the electron bunch. At all times during the collision a given positron sees the same cross section area for the electrons depending on the distance of the positron from the head of the positron bunch. Therefore, the adverse effects can not be compensated in the SR. The kink instability affects collisions with a non-zero offset.

The problem has been considered many times since the Hollebeek paper⁹ both analytically and numerically, but mostly for symmetric collisions. The situation for the asymmetric collisions is very different from that in storage rings and, in a sense, is simpler. Qualitative consideration of the dynamics of the collision is analytically allowed using a simple model although the importance of numeric study of the problem can not be overestimated. It should be noted, however, that such simulations have to include the dynamics of the distorted beam in the storage ring rather than the beam dynamics at collision only.

If the transverse rms bunch sizes at the IP are matched $\sigma_{ex} = \sigma_{px}$, $\sigma_{ey} = \sigma_{py}$, then the luminosity

$$L = \frac{N_e N_p f}{4\pi \sigma_{px} \sigma_{py}}. \quad (15)$$

On being expressed in terms of N_e and the electron disruption parameter $D_{e,y}$, where

$$D_{e,y} = \frac{2r_0 N_p \sigma_{pz}}{\gamma_e \sigma_{p,x} \sigma_{p,y}} \quad (16)$$

Eq. (15) takes the form:

$$L = \frac{N_e f \gamma_e D_{e,y}}{8\pi r_0 \sigma_{pz}}. \quad (17)$$

The repetition rate f is limited by the multibunch instabilities, power limitations, and the rise time of the kickers. Assuming $N_e = 0.5 \cdot 10^9$, $f \leq 20$ MHz, and $\gamma_e = 6.0 \cdot 10^3$, we obtain

$$L = \frac{10^{34}}{117.3 (\sigma_{pz}/\text{mm})} \text{ cm}^{-2} \text{ sec}^{-1}. \quad (18)$$

Hence, the desired luminosity $L = 10^{34} \text{ cm}^{-2} \text{ sec}^{-1}$ may be achieved with CEBAF-type linac and for the bunch length $\sigma_{p,z}$ of the order of 1 mm, only if $D_{e,y} \simeq 120$. This is at least two orders of magnitude larger than that usual in storage rings. The feasibility of the collisions with such large disruptions has to be studied very carefully.

At the same time, the disruption parameter is small for positrons because the number of electrons per bunch is about two orders of magnitude lower than that for positrons. In this case, in the first approximation we may neglect the disruption of the positron beam. For simplicity we additionally assume flat beams. In this case the

electric field of a bunch only has a vertical component E_y and is defined by the density ρ (normalized to one) of the encountering bunch:

$$\frac{\partial E_y}{\partial y} = 4\pi e N_p \rho(x, y, s, t). \quad (19)$$

Let us consider first a collision of an electron with a rigid positron bunch. We assume that the distribution of particles in a positron bunch

$$\rho(z, x, y) = \rho(z)\rho(x)\rho(y)$$

is Gaussian in the transverse directions

$$\rho(x) = \frac{e^{-x^2/2\sigma_x^2}}{\sqrt{2\pi\sigma_x^2}}.$$

For simplicity we assume the Gaussian longitudinal distribution:

$$\rho_z(z) = \frac{1}{\sqrt{2\pi\sigma_{pz}^2}} e^{-z^2/2\sigma_{pz}^2}. \quad (20)$$

The equation of motion in the y -plane for an electron is

$$m\gamma_e \frac{d^2 y}{dt^2} = -2eE_y(s, y, t)|_{x=0, s=ct+z_e}.$$

Here z is the distance of the electron from the center of the electron bunch ($z > 0$ for the head of the bunch), and the factor 2 takes into account the magnetic field of the positron bunch. Eq. (19) and Eq. (20) give

$$\frac{d^2}{ds^2} \left(\frac{y}{\sigma_{py}} \right) + \frac{2D_e}{\sigma_{pz}} \rho_z(2s + z_e) \int_0^{y/\sigma_{py}} dy e^{-y^2/2} = 0 \quad (21)$$

where D_e is defined in Eq. (16). More accurate calculations only replace σ_{px} in Eq. (16) with $\sigma_{px} + \sigma_{py}$.

The solution of Eq. (21) gives the trajectory of an electron in the form

$$y_e(s, z_e) = f \left(y_0, y'_0, \left(\frac{s + z_e/2}{\sigma_{pz}} \right) \right) \quad (22)$$

where y_0 and y'_0 are the initial conditions for the trajectory at $s \rightarrow -\infty$.

For small y , Eq. (21) is the equation of plasma oscillations:

$$y'' + k^2(s + z_e/2)y = 0,$$

where

$$k^2(z) = \frac{2D_e}{\sigma_{pz}} \rho_z(2z). \quad (23)$$

The total number of oscillations during the collision is

$$n_{osc} = \int_{-\infty}^{\infty} \frac{k ds}{2\pi} = 0.252 \sqrt{D_e}. \quad (24)$$

(The coefficient is $(2\pi)^{-3/4}$). At the center of the positron bunch, the amplitude of the oscillations adiabatically decreases as $1/\sqrt{k(s)}$ due to increasing density. The positron bunch may be considered as a "transport line". The beta function of the line $1/k(s)$ is on average

$$\beta_{eff} = \left(\frac{1}{2\pi} \right) \left(\frac{2\sigma_{pz}}{n_{osc}} \right) = 1.26 \frac{\sigma_{pz}}{\sqrt{D_e}}. \quad (25)$$

The frequency of plasma oscillations rapidly decreases with increasing amplitude $y_e(-\infty)$ as is clear from the expansion of the second term in Eq. (21) over y . For very large $y \gg \sigma_{pz}$ Eq. (21) may be simplified to

$$\frac{d^2}{ds^2} \left(\frac{y}{\sigma_{p,y}} \right) + \frac{D_e \sqrt{2\pi}}{\sigma_{pz}} \rho(2s + z_e) = 0. \quad (26)$$

Oscillations disappear if an electron trajectory crosses the line of collisions $y = 0$ at $s > \sigma_{pz}$ behind the positron bunch. It is easy to find from Eq. (26) that this happens for the trajectory with the initial condition $y(-\infty) = y_0$, $y'(-\infty) = 0$ for

$$y_0 \simeq D_e \sigma_{p,y}. \quad (27)$$

For the trajectories with $y(-\infty) < y_0$ there is at least one crossing point.

An example of trajectories found by numeric integration of Eq. (21) is shown in Fig. 3 for zero initial emittance and disruption parameter $D_e = 120$. The number of oscillations and nodes of the function f in Eq. (22) agrees with the estimate Eq. (24). The frequency of the nonlinear oscillations ought to decrease for large amplitudes. Hence, decoherence of the oscillations is expected, as depicted in Figures 4 and 5. The initial conditions are chosen in such a way that free particles are focused to match the transverse size of the positron bunch at the IP having the beam divergence $\beta_y^* = \sigma_{p,z}$. Decoherence, as well as the nodes in the distribution of the electrons, is explicit.

The nodes may drastically affect the dynamics of the positrons. The equation of motion for a positron is

$$m\gamma_p \frac{d^2 y}{dt^2} = -2eE_y(s, x, y, t)|_{x=0, y=y_p(t), s=-ct-z_p} \quad (28)$$

where z_p is the distance of the positron from the center of the bunch ($z > 0$ in the head of the bunch). The field here is given by the electron density ρ_e as in Eq. (19). The density at the moment t is the transform of the initial distribution ρ_0 in time:

$$\rho_e(x=0) = \int \frac{dy'_0 dy_0 dz_0}{\sqrt{2\pi\sigma_{ez}^2}} \rho_0(y_0, y'_0, z_0) \delta(y - y_e(y_0, y'_0, z_0, t)) \delta(s - s_e(y_0, y'_0, z_0, t)).$$

Fig. 3. Pinch of a beam with zero emittance: electron trajectories along the IR.

Fig. 4. Disruption of the electron beam with nonzero emittance. Decoherence is the result of the dependence of the plasma frequency on the amplitude of the oscillations for the Gaussian bunch. The choice of the initial conditions is explained in the text.

$$z = -3.02 \quad D = 120.0 \quad sy/\sigma_p = 1.00 \quad \sigma_{yp} = 1.00 \quad \alpha_{ph} = 0.00$$

Fig. 5. Transverse rms beam size along the IR for an unmatched beam of Fig. 4.

Here $s_e(y_0, z_0, t) = z_0 + ct$, and

$$y_e(y_0, y'_0, z_0, t) = f\left(y_0, y'_0, \left(\frac{ct + z_0/2}{\sigma_{pz}}\right)\right)$$

are the electron trajectory, see Eq. (22). For small N_e we can neglect the transverse motion of a positron during the collision: $y_p(t) = y_p$. Considering for simplicity $y_p > 0$ we obtain after integration over z_0 and y :

$$eE_y(x=0, s=-vt-z_p, y=y_p) = \frac{4\pi e^2 N_e}{\sqrt{2\pi\sigma_{ez}^2}} \int dy'_0 dy_0 \rho_0(y_0, y'_0, z_0 = -2ct - z_p) \Theta\left[y_p > f\left(y_0, y'_0, \left(\frac{-z_p}{2\sigma_{pz}}\right)\right) > 0\right]. \quad (29)$$

Here $\Theta[.] = 1$ if the condition in the brackets is fulfilled, and $\Theta[.] = 0$ otherwise. Let us assume the factorized distribution $\rho_0(y_0, y'_0, z_0) = \rho_z(z_0)\rho_\perp(y_0, y'_0)$ and Gaussian distribution in y_0 . Eq. (11) takes the form:

$$\frac{d^2 y_p}{ds^2} + \frac{2D_p}{\sigma_{ez}} \rho_z(2s + z_p) \int dy_0 dy'_0 \rho(y'_0) e^{-y_0^2/2\sigma_{ez}^2} \Theta\left[y_p > f\left(y_0, y'_0, \left(\frac{-z_p}{2\sigma_{pz}}\right)\right) > 0\right] = 0. \quad (30)$$

Where D_p is the disruption parameter for positrons:

$$D_p = \frac{2r_0 N_e \sigma_{ez}}{\sigma_{ez} \sigma_{ey} \gamma_p}. \quad (31)$$

For small D_p the collision does not change y_p giving a positron the kick

$$\Delta y'_p = -\frac{D_p}{\sigma_{ez}} \int dy_0 dy'_0 \rho(y'_0) e^{-y_0^2/2\sigma_{ez}^2} \Theta \left[y_p > f \left(y_0, y'_0, \left(\frac{-z_p}{2\sigma_{pz}} \right) \right) > 0 \right]. \quad (32)$$

The kick depends on the position of the positron in the bunch z_p and the number of the electron trajectories with offsets $y_0 < y_p$ at a given z_p . Let $(y_0)_{max} = \phi(-z_p/2\sigma_{pz})$ be the envelope of the electron trajectories at the given z_p . Then, an estimate of the integral Eq. (32) gives

$$\Delta y'_p = -\frac{D_p}{\sigma_{e,z}} \min \left\{ \frac{y_p}{\phi(-z_p/2\sigma_{pz})}, \sigma_{ey} \sqrt{\frac{\pi}{2}} \right\}. \quad (33)$$

The envelope $\phi = 1$ for small D_e . Hence, in this case Eq. (33) gives

$$\Delta y'_p = -\frac{D_p}{\sigma_{e,z}} y_p \quad (34)$$

corresponding to a thin lens with focal length $\sigma_{e,z}/D_p$. This gives a tune shift $\Delta\nu = \xi$, where the beam-beam parameter ξ is related to D_p :

$$\xi_{py} = \frac{D_p \beta_{py}^*}{4\pi \sigma_{e,z}}. \quad (35)$$

The maximum value of $\Delta y'_p$ given by the second term in Eq. (33) is less than the natural divergence of the trajectories in the beam at the IP $y'_{nat} = \sigma_{p,y}/\beta_{p,y}^*$ if

$$\xi_{py} < \frac{1}{(2\pi)^{3/2}} \frac{\sigma_{py}}{\sigma_{ey}} = 0.06 \frac{\sigma_{py}}{\sigma_{ey}}. \quad (36)$$

For $\sigma_{p,y} = \sigma_{p,z}$ the usual constraint $\xi_{p,y} < 0.06$ is obtained.

For large D_e , λ is large near the nodes of the function ϕ . Positrons located in the bunch in the vicinity of the nodes are unstable. For large electron disruption parameters D_e the number of nodes increases, but it is enough to have a single node to lose positrons. The synchrotron motion shuffles positrons along the bunch and pumps new positrons to the nodes where they get lost. Instability means diffusion to larger transverse amplitudes. The rate of the diffusion is affected by the synchrotron motion and is stabilized by the synchrotron radiation, but these effects are too weak to change the dangerous situation.

Transverse instability of positrons around the nodes generates a periodic perturbation of the longitudinal density in the positron bunch with the wave length $2\pi/k$:

$$\rho(s) = \rho_0[1 + \Delta \cos(ks)]. \quad (37)$$

Because k^2 in the equation of motion for electrons with small amplitudes Eq. (23) depends on $\rho(2s)$, the linearized equation of motion takes the form typical for the parametric resonance:

$$y'' + k^2[1 + \Delta \cos(2ks)]y = 0. \quad (38)$$

Thus, the well known "kink instability" may result. When the electron beam is dumped out after a collision the kink instability should not cause a problem.

For collisions with large D_e , synchrotron radiation is a serious problem. The radius of curvature R for a trajectory $y(s)$ is

$$\frac{1}{R} = -y'' = \frac{2D_e\sigma_{p,y}}{\sigma_{p,z}}\rho(2s)\int_0^{y/\sigma_y} dt e^{-t^2/2}. \quad (39)$$

Minimum R corresponds to $y \geq \sigma_{p,y}$. The maximum energy loss during the collision

$$\Delta E = \frac{1}{3}r_0\gamma_e^4 \int ds(1/R)^2 \text{ MeV} \quad (40)$$

is proportional to

$$\int ds(1/R)_{\max}^2 \simeq \left(\frac{D_e\sigma_{p,y}}{\sigma_{p,z}}\right)^2 \frac{\sqrt{\pi}}{2\sigma_{p,z}}. \quad (41)$$

The variation in the invariant mass

$$\frac{\Delta M}{M} \simeq \frac{r_0}{6}\gamma_e^3 \left(\frac{D_{ey}\sigma_{py}}{\sigma_{pz}}\right)^2 \frac{\sqrt{\pi}}{2\sigma_{pz}} \quad (42)$$

is less than $0.5 \cdot 10^{-3}$ if

$$\frac{D_{ey}\sigma_{py}}{\sigma_{pz}} < 6.63 \cdot 10^{-2} \sqrt{\sigma_{p,z}/\text{mm}} \quad (43)$$

giving a limitation on $\sigma_{p,y}$.

The size of the effect of synchrotron radiation on the decoherence of the electron oscillations has to be studied separately.

Variation of the transverse momentum is not so significant. If an electron has momentum $\vec{p} = -\vec{p}_0 + \vec{\Delta p}$ where $\Delta p = p_0\theta$ then

$$\frac{\Delta M}{M} \simeq \frac{\theta^2}{8}.$$

Estimating θ as

$$\theta \simeq 2\sigma_{py}n_{osc}/\sigma_{pz}$$

we found that $\Delta M/M \simeq 10^{-3}$ if

$$\frac{\sigma_{p,y}}{\sigma_{p,z}} \sqrt{D_{ey}} < 0.18. \quad (44)$$

BEAM MATCHING*

The feasibility of collisions with large electron disruption $D_e \gg 1$ might be questioned due to the instability of positrons at the nodes of the electron distribution. However, there are at least three reasons to expect that narrow waists in the electron

* Prof. N. Kroll mentioned to one of us (S. H.) that he suggested the idea of matching at the workshop at Blois, June 1989.

distribution may be avoided: nonlinearity of the oscillations, dependence of the phase of the oscillations on the location of an electron in the electron bunch, and synchrotron radiation.

The effect of the pinching of the electron beam on the stability of positrons can be minimized by the proper choice of the initial conditions for the electron beam entering the interaction region (IR). The simplest way to find the best initial conditions would be to track an electron bunch, matched to the positron bunch at the IP, back to the beginning of the IR. However, for $D_e \gg 1$ this method does not work due to the instability of the electron trajectories. We use the following approach. Let us specify the ellipse of the electron beam

$$\left(\frac{y}{\sqrt{2\epsilon/k}} \right)^2 + \left(\frac{y' + \alpha y}{\sqrt{2\epsilon k}} \right)^2 = 1 \quad (45)$$

where $\alpha = k'/2k$, and

$$k^2(s) = \frac{D_e}{\sigma_{p,z}^2} \sqrt{\frac{2}{\pi}} e^{-2(z/\sigma_z)^2}. \quad (46)$$

If two bunches are matched at the IP: $\sigma_{e,y}^2 = \langle y^2 \rangle = \sigma_{p,y}^2$ where $\alpha = 0$ then the emittance and $\sigma'_{p,y}$ are defined:

$$\epsilon = k(0)\sigma_{p,y}^2, \quad \sigma_{y'} = k(0)\sigma_y. \quad (47)$$

For large D_e , close to the center of the positron bunch, electrons oscillate rapidly. As long as

$$\left| \frac{d}{ds} \frac{1}{k(s)} \right| \ll 1 \quad (48)$$

emittance is preserved and the ellipse changes adiabatically.

Eq. (48) is valid for

$$k < k_{min} \simeq \frac{2}{\sigma_{p,z}}, \quad |z| < z_{min} = \sigma_{pz} \ln \left[\frac{k(0)}{2k_{min}} \right]. \quad (49)$$

The ellipse on the phase plane at $z = z_{min}$ is given by Eq. (45) with $k = k_{min}$. For larger $|z|$ the positron density decreases, and oscillations degenerate into free motion:

$$y = y_{min} + (z - z_{min})y'_{min}, \quad y' = y'_{min}.$$

Therefore the ellipse at the first quad of the IR is defined, i.e. at $z = -L$:

$$\left(\frac{y + ly'}{\sqrt{2\epsilon/k_{min}}} \right)^2 + \left(\frac{y' + \alpha_{min}(y + ly')}{\sqrt{2\epsilon k_{min}}} \right)^2 = 1 \quad (50)$$

where $l = L - z_{min}$.

In the simulations the initial conditions at $z = -L$ for Eq. (21) have been generated by

$$y = \sigma_\xi(1 + \alpha_{\min}l)\xi - \sigma_\eta l\eta$$

$$y' = -\sigma_\xi \alpha_{\min} \xi + \sigma_\eta \eta$$

where ξ and η are random numbers uniformly distributed in the interval from -1 to 1 , and

$$\sigma_\xi = \sigma_{py} \sqrt{\frac{2k(0)}{k_{\min}}}, \quad \sigma_\eta = \sigma_{p,y} \sqrt{2k(0)k_{\min}}, \quad \text{and} \quad \alpha_{\min} = \alpha(k_{\min}).$$

The trajectories given by Eq. (21) and these initial conditions are shown in Fig. 6 for $D = 120$. The pinches have almost disappeared, and the distribution of electrons within the interaction area $|z| < \sigma_{p,z}$, $|y| < \sigma_{p,y}$ is practically uniform. The result is robust: small variations of $k_{\min}$ do not change this result significantly. Fig. 7 shows that the longitudinal variation of the transverse rms size σ_y of the electron beam is small for $k_{\min}\sigma_{pz} \simeq 2$. The absolute value of $y(-L)$ and $y'(-L)$ are moderate:

$$y(-L) \simeq \sigma_{p,y} \left(\frac{L}{\sigma_{p,z}} \right) D^{1/4}, \quad y'(-L) \simeq \left(\frac{\sigma_{p,y}}{\sigma_{p,z}} \right) D^{1/4}. \quad (51)$$

Practically, $y(-L)$ is of the order of a mm. Figures 8 and 9 are the same as Figures 6 and 7 but for $D = 360$.

Fig. 6. Trajectories for the matched beam. $D_e = 120.0$. The electron distribution within $|z| < 2\sigma_z$, $|y| < \sigma_{p,y}$ is rather uniform.

$$z = -3.02 \quad D = 120.0 \quad sy/\sigma_p = 3.13 \quad \sigma_{yp} = 6.26 \quad \text{alph} = 1.26$$

Fig. 7. Variation of the rms $\sigma_{e,y}$ for the matched electron beam along the IR; trajectories are shown in Fig. 6. $D_e = 120.0$.

$$z = -3.02 \quad D = 360.0 \quad sy/\sigma_p = 4.12 \quad \sigma_{yp} = 8.23 \quad \text{alph} = 1.46$$

Fig. 8. The same as in Fig. 6 for $D_e = 360.0$

$$z = -3.02 \text{ D} = 360.0 \quad sy/\sigma_p = 4.12 \quad \sigma_{py} = 8.23 \quad \alpha = 1.46$$

Fig. 9. The same as in Fig. 7 for $D_e = 360.0$

Therefore, assume that collisions with large disruption parameters are feasible. We will use the dimensionless bunch length and the SR emittance

$$\zeta = \sigma_{pz}/\text{mm}, \quad \epsilon = \epsilon_{px}/\text{nm} \quad (52)$$

and consider electron bunches with $N_e = 0.5 \cdot 10^9$ per bunch. Then the remaining parameters may be chosen in the following way. To get $L = 10^{34} \text{ cm}^2/\text{sec}$ the disruption parameter has to be (see Eq. (18))

$$D_{e,y} = 108.65 \zeta. \quad (53)$$

Eq. (43) then gives the relation between σ_{pz} and σ_{py} :

$$\sigma_{py} = 0.61 \sqrt{\zeta} \text{ } \mu\text{m}. \quad (54)$$

Introducing the aspect ratio of the beam sizes in the SR $R_p^2 = \epsilon_{px}/\epsilon_{py}$ we obtain

$$\beta_{py}^* = R_p^2 \beta_{pz}^* \left(\frac{\sigma_{py}}{\sigma_{pz}} \right)^2. \quad (55)$$

To avoid degrading the luminosity, the divergence of the positron beam near the IP has to be limited:

$$\beta_{pz}^* \geq \sigma_{pz}. \quad (56)$$

Bunch rotation could be used to change the bunch length prior to a collision. That, however, would increase the energy spread of the positrons σ_δ and decrease the average luminosity

$$L \propto \Gamma(Y)/\sigma_\delta$$

Eq. (61), (64) and Eq. (65) define all parameters as function of R_p . For $R_p = 10$ we obtain

$$\epsilon = 5.75, \quad \kappa = 0.454, \quad \zeta = 3.33.$$

This defines

$$\epsilon_{p,x} = 5.75 \text{ nm}, \quad \sigma_{px} = 4.37 \text{ } \mu\text{m}, \quad \sigma_{py} = 1.11 \text{ } \mu\text{m}$$

$$\beta_{px}^* = 3.33 \text{ mm}, \quad \beta_{py}^* = 21.55 \text{ mm}.$$

The disruption parameter is $D_{e,y} = 361.8$. Eq. (13), (11) and $\kappa = 0.454$ specify the lattice parameter in the SR:

$$\alpha \sigma_\delta^2 = 1.2 \cdot 10^{-8}.$$

The energy spread has to be comparable with the width of the Υ resonance. Choosing $\sigma_\delta = 2.45 \cdot 10^{-3}$ we obtain the compaction parameter

$$\alpha = 2.0 \cdot 10^{-3}.$$

Parameters of the storage ring ϵ_{px} , α , and σ_δ are close to the sample lattice given before. The ring requires 70.68 cells of that type, with the total length 353.43 m. This is consistent with the circumference of the ring being 450 m, the parameter which has been used for the estimate. The radiated power is 7.77 MeV/turn/particle. The emittance of the electron beam is approximately

$$\epsilon_{e,y} = k(0) \sigma_{p,y}^2 = \sigma_{py}^2 \frac{\sqrt{D_{e,y}}}{\sigma_{pz}} \left(\frac{2}{\pi} \right)^{1/4} \quad (66)$$

or $\epsilon_{e,y} = 5.66 \text{ nm}$. The disruption parameter in the horizontal plane is σ_{py}/σ_{px} times smaller than $D_{e,y}$. Consequently

$$D_{e,x} = 92.0, \quad \text{and} \quad \epsilon_{e,x} = 49.1 \text{ nm}.$$

PARAMETERS

A final set of parameters is as follows:

Linac:

$$E_e = 3.5 \text{ GeV}$$

$$N_e = 0.544 \cdot 10^9$$

$$I_{av} = 1.6 \text{ mA}$$

$$f_{RF} = 1.5 \text{ GHz}$$

$$l_z^e = 2.2 \text{ psec}$$

$$\epsilon_{e,y} = 5.66 \text{ nm}; \epsilon_{e,x} = 49.1 \text{ nm}$$

$$P = 5.65 \text{ MW}$$

$$\text{power loss} = 2.0 \text{ W/cav}$$

$$\text{repetition rate} = 20 \text{ MHz}$$

SR:

$$E = 8.0 \text{ GeV}$$

$$I_{aver} = 1.94 \text{ A}$$

$$N_B = 6.1 \cdot 10^{11}$$

$$n_B = 30$$

$$S_B = 15 \text{ m}$$

$$P = 15.1 \text{ MW}$$

$$n_{cav} = 50$$

$$E' = 2.5 \text{ MeV/cavity}$$

$$C \simeq 450 \text{ m}$$

$$R_p = 10$$

$$\epsilon_{p,x} = 5.75 \text{ nm}, \quad \epsilon_{p,y} = 0.057 \text{ nm}$$

$$\alpha = 2.0 \cdot 10^{-3}$$

$$\sigma_\delta = 2.45 \cdot 10^{-3}$$

$$\sigma_z^p = 3.33 \text{ mm}$$

$$(Z/n)_{tot} = 0.5 \text{ Ohm}$$

$$\rho_{bend} = 45 \text{ m}$$

$$\tau_x = 0.9 \text{ msec}$$

$$\tau_y = 2.4 \text{ msec}$$

$$\tau_\delta = 6.9 \text{ msec}$$

$$L_{cell} = 5 \text{ m}$$

$$\beta_x = 9.8 \text{ m}, \beta_y = 1.4 \text{ m}, D_x = 0.255 \text{ m}$$

Collisions:

$$L = 10^{34} \text{ cm}^{-2} \text{ sec}^{-1}$$

$$D_{ey} = 361.8, \quad D_{pe} = 6 \cdot 10^{-3}$$

$$\xi = 0.06$$

$$\text{rep. rate } 20 \text{ MHz}$$

$$\beta_{e,y}^* = \beta_{p,x}^* = 3.33 \text{ mm}$$

$$\beta_{p,y}^* = 21.55 \text{ mm}$$

$$\sigma_{e,x}^D = \sigma_{p,x}^* = 4.37 \text{ } \mu\text{m}$$

$$\sigma_{e,y}^D = \sigma_{p,y}^* = 1.11 \text{ } \mu\text{m}$$

$$\text{beam size at 1 m from IP } y = 1.45 \text{ mm}$$

DISCUSSION

A beauty factory based on a SRF linac with CEBAF parameters can be designed only with very large disruption parameters. We have presented arguments and results of model simulations which indicate that such a design may be feasible. Confirmation that the kink instability is suppressed would be a significant argument in favor of the asymmetric collisions. Much more elaborate simulations are needed before a sound statement may be made but the situation does not look hopeless. With this implication we give as an example a consistent set of parameters for the B-factory with asymmetric kinematics of collisions and luminosity 10^{34} cm²/sec.

A lattice with low emittance, large compaction factor and large energy spread is necessary. Test lattices have been designed with parameters close to those specified. A new tunnel will be necessary for the SR, but the parameters of the CEBAF-type linac are satisfactory. The existing CEBAF cavities can be used; only additional power has to be added.*

There are many problems to study: design of the lattice, injector, and the interaction region, the minimum value of the impedance possible in the SR, multibunch stability in the SR, dynamic aperture and acceptance of the SR, the enhancement factor of asymmetric collisions, etc. Nevertheless, a linac-SR scheme promises very high luminosity and seems to be feasible.

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* J. Bisognano noticed that the resetting of the external Q might be necessary as well to decrease the reflected power.