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APIARY B-Factory Separation Scheme*

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Abstract

A magnetic beam-separation scheme for an asymmetric-energy B-Factory based on the SLAC electron-positron collider PEP is described that has the following properties: the beams collide head-on and are separated magnetically with sufficient clearance at the parasitic crossing points and at the septum, the magnets have large beam-stay-clear apertures, synchrotron radiation produces low detector backgrounds and acceptable heat loads, and the peak β−function values and contributions to the chromaticities in the IR quadrupoles are moderate.

I. Introduction

The APIARY B-Factory design calls for electrons and positrons to be stored in two rings, separated vertically, and located in the PEP tunnel. The 2-ring system is forced by the high currents and small bunch spacing required for high luminosity. The parameters of the system are shown in Table 1.

Table 1. APIARY Parameters

	Low Energy Beam	High Energy Beam	
Energy	3.1	9.0	GeV
Current	2.14	1.48	A
Betas at IP, β_x/β_y	37.5/1.5	75.0/3.0	cm
Emittance, $\varepsilon_x/\varepsilon_y$	96.5/3.9	48.2/1.9	nm-rad
Bunch separation	1.26	1.26	m
Vertical separation	0.895		m
Collision mode	head on		
Separation scheme	magnetic: horizontal, then vertical		
IP aspect ratio, $\sigma_x:\sigma_y$	25:1		
Luminosity	3×10^{33}		$cm^{-2}\ sec^{-1}$

The separation scheme must solve three interwoven problems: to separate the beams and lead them into the two rings, to focus the beams without unacceptable β−function values or chromaticity contributions, and to control the quantity and distribution of synchrotron radiation (SR) produced so that sensitive components can be shielded by the masking system.

II. Description of the Separation Scheme

The separation scheme is briefly as follows: the beams collide head-on and are separated after leaving the interaction point (IP) by the dipole magnet B1 starting 20 cm from the IP, a triplet common to both beams with quadrupoles QD1, QF2, and QD3 centered alternately on the high, low and high energy beams to increase the separation, a septum quadrupole QD4 focussing the high-energy beam (HEB) only, and a vertical septum dipole that deflects the low-energy beam (LEB) upwards, see Figs. 1-3. This dipole together with three others beyond bring the LEB to a level 89.5 cm above the HEB. Seven quadrupoles between these vertical bends focus the LEB and bring the horizontal and vertical dispersions to zero. Just beyond the vertical septum, the quadrupole QF5 focusses the HEB horizontally (see Fig. 4), and bending magnets begin the steering of that beam toward the arc and contribute to the dispersion suppression. Additional horizontal dipoles and quadrupoles in both beamlines complete the steering, dispersion matching, and matching of the beams to the β functions in the arcs.

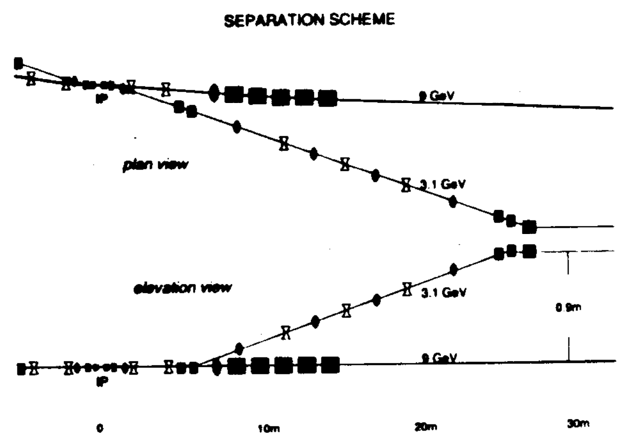

Figure 1. Schematic diagram of the APIARY separation scheme.

The system design satisfies the following constraints:

- The beam-stay-clear (BSC) in the interaction region (IR) magnets is defined to contain both beams with $15\sigma_{x,y}$ envelopes, plus 2 mm for orbit distortion, where σ_x, σ_y refer to uncoupled, fully-coupled beams respectively
- At least 2 mm spacing between SR fans and the nearest surface
- A 5 mm allowance for beam pipe, cooling, and trim coils between the BSC and SR fans and any magnetic material
- The ratio β_y^*/(distance to 1st quadrupole) ~ 100, in order to keep the chromaticity reasonable
- 15 mm is allowed for the QF4 septum between the BSCs of the two beams

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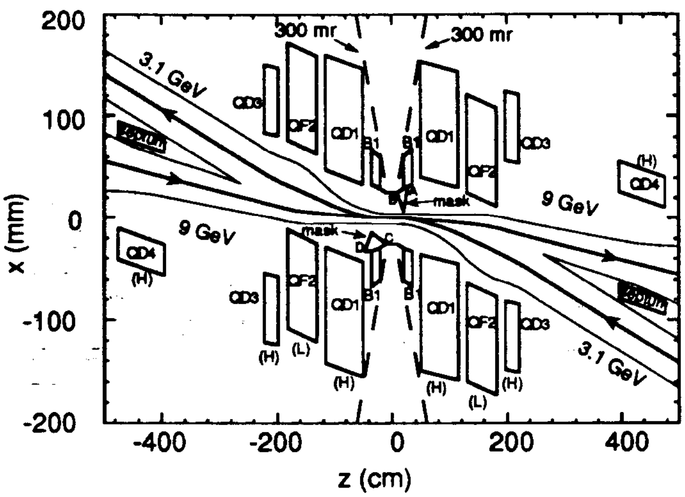

Figure 2. Plan view of the magnets and beamlines near the IP. Note the distorted scale.

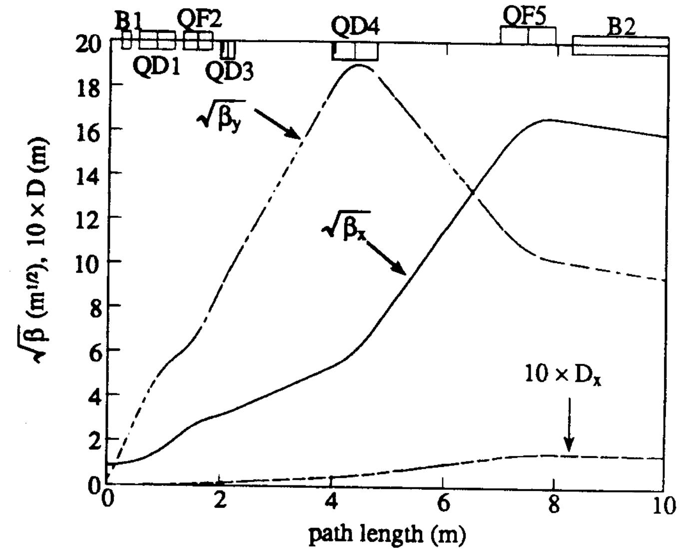

Figure 4. Lattice functions of the HEB within the first 10 m of the IP.

III. Optics, Beam Matching and Steering

The four common elements B1, QD1, QF2, and QD3 are permanent magnets, with 1.05 T remnant fields, and inner radii satisfying the BSC and other constraints listed previously. Fig. 2 shows a diagram of the IR in plan view. The beamlines are shown as heavy lines, and the $15\sigma_x$ envelopes as light lines. The (H) or (L) near each magnet indicates on which beam (HEB or LEB) the quadrupole is centered.

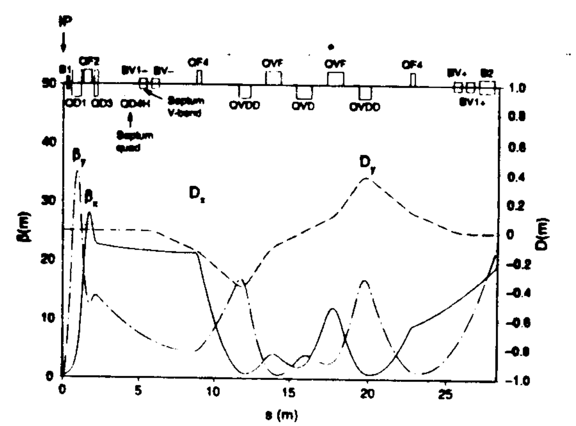

Figure 3. Lattice functions of the LEB from the IP to the end of the vertical step.

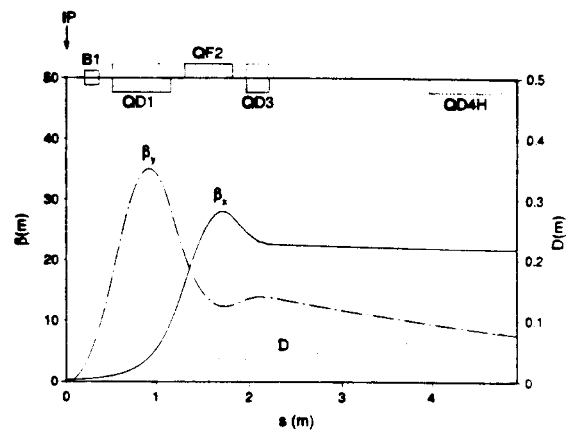

Figure 5. Lattice functions of the LEB through the common magnets and the septum quadrupole.

The triplet is adjusted to focus the LEB so that it is small at the QD4 septum and enters the vertical-step region in a nearly parallel state with small β–function values (see Fig. 5). The triplet is also quite useful for some initial focusing of the HEB. The quadrupole QD1, though centered on the HEB, is tilted with respect to it in order that one of the SR fans not strike its inner surface.

The first 'parasitic' bunch crossing point occurs 63 cm from the IP, just inside QD1, where the beamlines are separated by 7.5 times the largest σ-value of either beam (σ_x(LEB)).

The horizontal bending pattern is antisymmetric about the IP, which produces an S-bend beamline—a geometry that is conducive to extracting the synchrotron radiation.

Figure 6 shows the first 60 m from the IP to the start of the arc for the HEB. The dispersion function D and its slope are brought to zero by the dipoles B2 and B3 whose bending is very weak ($\epsilon_{crit} \approx 1$ keV) to avoid problems with the SR in the IR. These dipoles are followed by quadrupoles QD6 and QF7 that match the β functions into the arc. Two additional dipoles in the dispersion suppressor at the end of the arc steer the HEB to the proper direction.

The strength of the B2 dipole of the LEB (originally set to bring D_x and its slope D_x' to zero at the end of B2), together with the strengths of three additional dipoles, are adjusted to steer the LEB from the arc to the IP with the correct radial position and slope, while preserving the dispersion matching. The remaining β–function matching for the LEB, is done with quadrupoles QD8-QF13, located between the end of the vertical step and the arc.

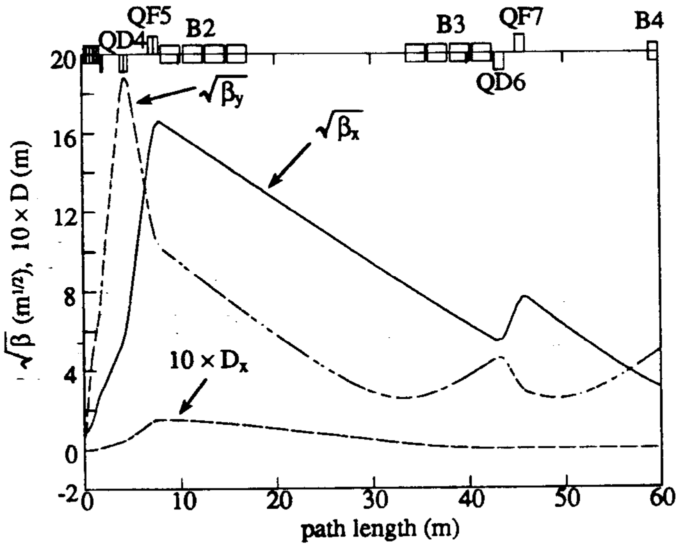

Figure 6. Lattice functions of the HEB from the IP to the begining of the arc.

Table 2. Properties of the synchrotron radiation generated within ±3 meters of the IP.

Magnet	Fan pwr (kW)	$N_\gamma(10^{10})$	ε_{crit}(keV)
LEB:			
Upstream QD3	0.84	3.1	2.3
Upstream QD1	0.83	5.4	1.3
Upstream B1	2.39	4.2	4.8
Downstream B1	2.39	4.2	4.8
Downstream QD1	0.96	5.2	1.4
Downstream QD3	0.91	3.1	2.4
subtotal	8.3	13	
HEB:			
Upstream QF2	28.3	7.5	32.1
Upstream QD1	2.3	2.7	7.3
Upstream B1	13.8	2.9	40.4
Downstream B1	13.8	2.9	40.4
Downstream QD1	1.1	1.8	5.1
Downstream QF2	26.1	7.3	30.5
subtotal	85.4	25	
Total	93.7	38	

IV. Control of the Synchrotron Radiation

The LEB generates SR fans as it passes through QD3, QD1 and B1 on its way to the IP. Figure 7 shows the LEB radiation fans near the IP. The mask labeled AB in Figs. 7 and 8 is designed to prevent any SR generated by the upstream magnets from directly striking the detector beam pipe. The QD1 magnet, in the LEB downstream direction, is tilted with respect to the HEB axis by 22 mrad, so that any SR generated by the LEB upstream magnets that goes by the AB mask tip clears the beampipe.

As can be seen in Fig. 7, the AB mask absorbs all of the fan radiation from the upstream QD3 magnet. The fans generated by the two B1 dipoles and by the downstream QD1 and QD3 magnets pass through the IR without striking any surfaces. The first surface that intercepts the QD1 fans is the "crotch mask" in front of the QD4 septum. Table 2 summarizes some of the properties of the LEB and HEB radiation fans.

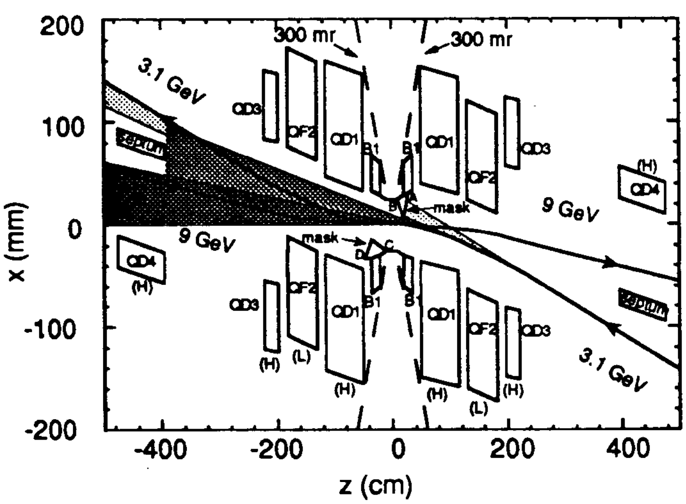

Figure 7. Radiation fans generated by the LEB near the IP. Darker shading indicates higher radiation intensity.

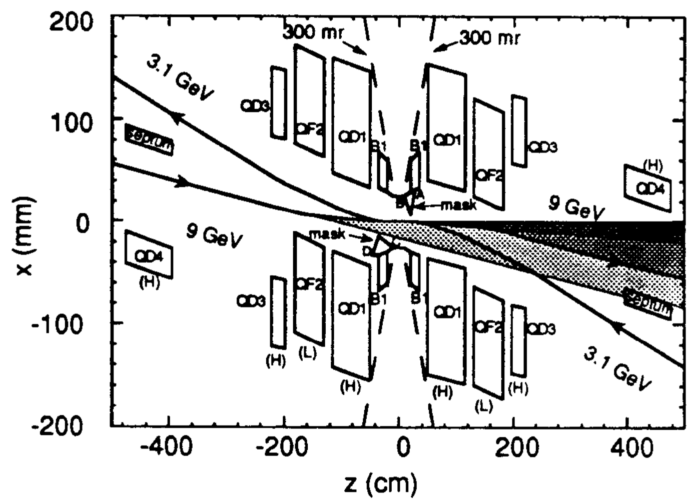

Figure 8. Radiation fans generated by the HEB near the IP.

The SR fans generated by the HEB as it passes through the QF2 and B1 magnets also pass through the detector region without striking any surfaces. Figure 8 shows the HEB radiation fans near the IP. The mask labeled CD in Figs. 7 and 8 is located to prevent quadrupole radiation produced by the HEB in QF5 and QD4 from directly striking the detector beam pipe. The CD mask tip is positioned 2 mm outside the upstream QF2 radiation fan that passes through the IR. The other QD1 magnet, in the HEB downstream direction, is tilted with respect to the HEB axis by 15 mrad, so that this fan clears the beampipe. Therefore the first surface struck by the upstream QF2 fan is the crotch mask in front of QD4.

Only 6% of the total generated SR strikes surfaces within 4 m of the IP: 4.3 kW on the crotch mask from the HEB and 1.2 kW on the AB mask from the LEB (see Table 2). This leads to an estimated detector background level that is 50 times lower than acceptable limits.