SLAC–PUB–5637
August 1991
(A)

B–FACTORIES*

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ABSTRACT

The evolution of B-Factories is discussed, and comments are made about the common features of present-day asymmetric storage ring collider designs.

* Work supported by Department of Energy contract DE–AC03–76SF00515.

Presented at the 4th International Symposium on Heavy Flavour Physics,
Orsay, France, June 25–29, 1991

There was a symposium *Progress on B-Factories* the day before the *Heavy Flavour Symposium.* There the B-Factory designs being considered by six laboratories were presented and discussed. This paper is a brief summary of these designs and the evolution that led to them having many common features.

A "B-Factory" was defined broadly a few years ago as an e^+e^- collider with sufficient luminosity that CP violation in B decays could be detected. Five different B-Factories were compared at Snowmass in 1988:[1] 1) An asymmetric collider (unequal beam energies) at the $\Upsilon(4S)$,[2] 2) A collider with equal beam energies (a symmetric collider) operating just above the $\Upsilon(4S)$, 3) A collider at $\sqrt{s} \approx 16$ GeV, 4) A collider at the Z with unpolarized beams, and 5) A collider at the Z with a polarized electron beam. This comparison together with the scale of colliders at the Z have led to everybody concentrating on the $\Upsilon(4S)$ region. Many independent studies came to the conclusion that storage rings could reach the luminosity needed, $L \sim 3\times10^{33}\text{cm}^{-2}\text{s}^{-1}$, and there was no need to develop new types of colliders such as low-energy linear colliders or linac-storage ring colliders. The asymmetric collider has a significant luminosity advantage over the symmetric collider that comes primarily from the $\Upsilon(4S)$ resonance cross section. All laboratories are concentrating on asymmetric colliders with symmetric ones being backups only.

The designs whose parameters are given in Table I have a great deal in common (there are interesting differences in the details, but these are outside the scope of and audience for this paper). Offbeat ideas such as round beams and isochronous rings have been rejected as have unequal circumference rings. The latter was discarded because of coherent beam-beam effects,[3] the practical and political advantages of avoiding new civil construction, and preserving the options for a second detector and a symmetric collider. It was necessary to choose between a high and low collision frequency, f_c. Both require the same total current; the luminosity scales as $L \sim I_t \xi / \beta_v^*$ where I_t, ξ, and β_v^* are the total current, beam-beam tune-shift, and the vertical amplitude function at the collision point, respectively. A high f_c has the advantages of smaller single bunch currents and beam emittances while a low f_c has a smaller number of bunches and easier separation at the interaction region. Everyone has decided in favor of high collision frequency principally because the lower emittance is critical for reducing the backgrounds from synchrotron radiation.

Table I: Collider Parameters *

	CERN[4]	Cornell[5]	DESY[6]	KEK[7]	Novosibirsk[8]	SLAC/LBL/ LLNL[9]
Lumin(10^{33}cm^{-2}s^{-1})	1	3	3	2	5	3
Energies (GeV)	8.0,3.5	8.0,3.5	9.3,3.0	8.0,3.5	6.5,4.3	9.0,3.1
Total I's (Amp)	0.56,1.3	0.87,2.0	0.71,1.1	0.22,0.52	0.7,1.0	1.5,2.1
# of bunches	80	230	640	1024	170	1658
Bunch length (cm)	2.0,2.0	1.0,1.0	1.0,1.0	0.5,0.5	0.8,0.8	1.0,1.0
Peak I (kAmp)	0.13,0.31	0.12,0.26	0.10,0.15	0.05,0.12	0.15,0.15	0.08,0.11
RF volt (MV)	13.,2.0	35.,12.	17.,4.5	48.,22.	7.,4.5	18.,9.5
RF power (MW)	4.4,0.7	4.8,2.4	--,1.0	--	2.4,2.4	8.3,4.9
# of RF cells	20,4	12,4	31,9	60,28	6,6	20,10
RF technology	room temp	supercond	supercond	room temp	supercond	room temp
β_v* (cm)	3.0,3.0	1.5,1.5	2.0,1.0	1.0,1.0	1.0,1.0	3.0,1.5
β_h* (m)	1.0,1.0	1.0,1.0	0.4,0.2	1.0,1.0	0.6,0.6	0.75,0.38
η* (m)	0.0,0.0	0.0,0.0	0.0,0.0	0.0,0.0	0.4,0.4	0.0,0.0
ξ_v (10^{-2})	3.0,3.0	3.0,3.0	4.0,4.0	5.0,5.0	5.0,5.0	3.0,3.0
ξ_h (10^{-2})	3.0,3.0	3.0,3.0	4.0,4.0	5.0,5.0	1.2,1.2	3.0,3.0
ε_v (nm)	9.0,9.0	2.0,2.0	2.5,5.0	0.19,0.19	0.25,0.25	1.9,3.9
ε_h (nm)	300.,300.	130.,130.	50.,100.	19.,19.	5.,4.	48.,96.
σ_E/E (10^{-3})	0.84,0.52	0.84,0.65	--	0.72,0.77	1.,1.	0.61,0.95
σ_v (μm)	16.,16.	5.4,5.4	7.0,7.0	1.4,1.4	1.6,1.6	7.6,7.6
σ_h (μm)	550.,550.	360.,360.	140.,140.	140.,140.	400.,400.	190.,190.
Q_s (10^{-2})	5.5,3.4	8.5,8.5	--	--	2.3,2.3	5.2,5.0
δ (10^{-4})	7.0,0.86	6.5,2.2	3.7,2.1	5.3,2.7	4.2,3.5	4.0,4.0
Bunch space (m)	12.0	3.3	3.6	3.0	4.2	1.3
Separation	magnetic	angle	magnetic	magnetic	magnetic	magnetic

Symbols: h,v ≡ horizontal, vertical; β* ≡ amplitude function; η* ≡ dispersion; ξ ≡ beam-beam tune-shift; ε ≡ emittance; σ_E/E ≡ rms fractional energy spread; σ ≡ beam size; Q_s ≡ synchrotron tune; δ ≡ fractional energy loss between collisions.

* The parameters of the high energy ring are followed by those of the low energy ring.

The interaction region involves a set of complex, interconnected questions related to the beam-beam interaction, bunch spacing, method of separation, and backgrounds. All designs have chosen $\sigma_h \gg \sigma_v$ and $\sigma_{h,v}$(low energy) = $\sigma_{h,v}$(high energy) to have a collision configuration that resembles closely that of existing colliders. This is judged to reduce the uncertainty arising from the beam-beam interaction. Four of the six designs extend this idea of duplicating present-day collision geometries further by using head-on collisions with zero dispersion (η^*). The beams are separated by dipole magnets extremely close, ~ 20 cm, to the collision point. The Novosibirsk collider has magnetic separation but non-zero dispersion that allows for a reduction in center-of-mass energy spread,[10] and the Cornell proposal uses crab-crossing[11] - angle crossing with the beams tilted. Both bring novel features to the beam-beam interaction.

Backgrounds are the factor that has dominated the interaction region designs and, through these, the overall designs. The total current must be large for high luminosity, and vertex detection is critical for the CP violation measurements that are the raison d'être. These combine to present difficult background problems from two sources: degraded beam particles and synchrotron radiation. The former can be controlled by meeting stringent vacuum requirements for tens of meters around the interaction region. The latter must be solved by reducing the flux of synchrotron radiation photons and masking (shadowing) the beam pipe. Masking can be designed for small emittance beams because they are small in the large quadrupoles that focus the beams to the collision point, but masks have not been designed successfully for large emittance beams that would be large in these quadrupoles. This has driven the designs to high collision frequencies because the beam-beam tune-shift is limited by the beam-beam interaction. It is given by $\xi \sim I_s/(\varepsilon_v \varepsilon_h)^{1/2}$ where I_s is the single bunch current and the ε's are the emittances. With a restriction on emittance from backgrounds a small single bunch current is required. That raises the number of bunches and collision frequency since $L \sim I_t \xi / \beta_v^*$.

The total beam currents are large and there is need for careful attention to issues of beam produced heating, instabilities, vacuum, feedback, and RF systems. There is an enormous flux of synchrotron radiation photons striking the vacuum chamber walls in the arcs, and new techniques of surface preparation and pumping are needed to get an adequate vacuum. Coupled bunch instabilities are one of the potential costs of a large number of bunches. Their importance can be reduced with feedback and by lowering the quality factors of unwanted resonant modes in the RF system. These have been done in the past, but a B-Factory is especially demanding. RF systems are usually the Achilles' heel of electron-positron colliders, and extensive developing and prototyping of these systems is necessary. Justifiably, the issues associated with high currents are emphasized in those R&D plans that have been discussed to date.

In summary, there is agreement on the general approach to building an asymmetric B-Factory with the promise of reaching $L \sim 3\times10^{33}cm^{-2}s^{-1}$. Backgrounds have influenced the designs strongly, and the large beam currents require vacuum, feedback, RF systems that are state-of-the art. These B-Factory proposals are in various states of consideration by laboratories and governments. Given the progress in the past few years I am hopeful that there will be a B-Factory studying CP violation somewhere in the world.

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1. G. J. Feldman et al, *Proc. of Summer Study on High Energy Physics in the 1990's*, edited by S. Jensen (World Scientific, Singapore, 1989), p. 561.
2. P. Oddone, *Proc. of UCLA Linear-Collider $B\bar{B}$ Factory Concep. Design*, edited by D. H. Stork (World Scientific, Singapore, 1987), p. 423.
3. K. Hirata and E. Keil, CERN/LEP-TH/89-54 (CERN, 1989).
4. Feasibility Study for a B-Meson Factory in the CERN ISR Tunnel, CERN 90-02, PSI PR-90-08x.
5. CESR-B Conceptual Design for a B Factory Based on CESR, CLNS 91-1050.
6. F. Willeke et al, "A B-Factory in the PETRA Tunnel", 1991 IEEE Particle Accelerator Conference.
7. F. Takasaki, presentation at *Progress on B-Factories*, June 1991.
8. A. N. Dubrovin and A. A. Zholents, "A Combined Symmetric and Asymmetric B-Factory with Monochromatization", 1991 IEEE Particle Accelerator Conference.
9. An Asymmetric B Factory Based on PEP, LBL PUB-5303 etc.
10. I. Yà. Protopopov et al, INP 79-6 (Novosibirsk, 1979).
11. R. B. Palmer, SLAC-PUB-4707 (SLAC, 1988).
    K. Oide and K. Yokoya, Phys. Rev. **A40** 315(1989).