The Super B Factory

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1 Introduction

This contribution addresses the future of the study of quark physics in e^+e^- annihilation, at the $\Upsilon(4S)$and $\Upsilon(5S)$, over the next decade and beyond. A more detailed treatment can be found in Ref. [1].

The search for new physics in the quark sector involves direct searches for new particles (*e.g.* squarks), precise tests of standard model predictions for rare decay branching fractions and decay distributions to search for new amplitudes in loop processes, and overconstrained tests of the CKM matrix. A very high luminosity asymmetric B Factory can make unique contributions to these studies, as well as providing capabilities complementary to those of experiments at hadronic machines.

2 Physics Motivation and Capability

Precision tests of CKM unitarity require the percent level precision on the measurement of $\sin2\beta$ obtainable at a 10^{36} asymmetric B Factory as well as the several percent precision obtainable on $\sin2\alpha$ and $\sin2\gamma$ with very large samples of rare hadronic B decays. In particular, measurements of the separate branching ratios of $B(B^0 \to \pi^0\pi^0)$ and $B(\overline{B}^0 \to \pi^0\pi^0)$ decays, possible only at an e^+e^- B Factory, are vital to obtain a precise value of α with minimal theoretical assumptions [2],[3]. Taken together with concomitant improvements in our understanding of the magnitudes of CKM matrix elements, which require new techniques involving tagging and exclusive reconstruction of B semileptonic decays, as well as anticipated improvements in lattice gauge calculations, this program is capable of tests of CKM unitarity of exquisite precision. Measurements of the third angle γ are difficult, but can be done to excellent precision at a 10^{36} machine, both by the comparison of $b\to c\overline{u}s$ and $b\to u\overline{c}s$ decays using $B\to DK$ transitions at the $\Upsilon(4S)$[4], and measurements of $B_s\to D^{(*)\pm}K^{(*)\mp}$ decays at the $\Upsilon(5S)$ [5].

Table 1 summarizes the precision obtainable on the angles of the unitarity triangle at an experiment with 500 fb^{-1} and 10 ab^{-1}, corresponding to 1 year of running at

CKM Angle	*BaBar* (0.5 ab^{-1})	Super*BaBar* (10 ab^{-1})	BTeV†	LHCb	Atlas/CMS
sin2β ($B^0 \to J/\psi K_S^0$)	0.037	0.008	0.025	0.014	0.021/0.025
sin2β ($B \to \phi K_s$)	0.25	0.056			
sin2α ($B^0 \to \pi^+\pi^-$)	0.14	0.032	0.024	0.056	0.10/0.17
$\alpha_{\mathrm{Eff.}} - \alpha$ ($B^0 \to \pi^0\pi^0$)	$< 18°$	$< 7°$	-	-	-
$\sin(2\beta + \gamma)$ ($B^0 \to D^*\pi$)	0.15	0.03			
γ ($B \to DK$)	-	$< 2.5°$	$< 10.0°$	$< 19.°$	
γ ($B_s \to D_s K$)	-	$< 15°$	$< 7.0°$	$< 13.°$	

‡Two armed version of BTeV

Table 1: Summary of the estimated precision of CKM angle measurements for both *BABAR* and Super*BABAR*, compared to planned experiments at hadronic colliders.

10^{36} luminosity, with that obtainable with planned and proposed experiments at hadronic colliders. The determination of γ using the $\Upsilon(5S)$ requires a separate data set of 1 ab^{-1}. In general, multiple complementary measurements of the CKM angles are possible. The 10^{36} collider has the capability to measure all three *CP*-violating angles of the unitarity triangle to the level warrented by the precision of theoretical calculations.

Table 2 compares the sensitivity of experiments with 500 fb^{-1}, the target total sample for *BABAR*, and with 10 ab^{-1}, corresponding to 1 year of running at 10^{36} luminosity, with that obtainable with planned and proposed experiments at hadronic colliders. The 10^{36} collider compares quite favorably with hadronic experiments, in rare inclusive and exclusive modes, and particularly in radiative modes. Note also that only an e^+e^- experiment can produce a sample of tagged decays.

3 SuperPEP-II

The next generation asymmetric B Factory requires a significant increase in luminosity, approaching $10^{36}\mathrm{cm}^{-2}\mathrm{s}^{-1}$, well beyond the already record-setting performance of PEP-II and KEKB. It appears that such a luminosity is feasible; initial parameters of SuperPEP-II, a very high luminosity asymmetric B Factory are being developed, incorporating several new ideas from the successful operation of the present generation accelerators. In this regime, the luminosity lifetime is primarily determined by the collisions themselves, and is typically a few minutes, requiring continuous injection. This has a positive consequence: the ratio of average to peak luminosity in SuperPEP-II can be increased by 30% due to continuous injection, thereby directly improving the ability to integrate luminosity. In fact, with continuous injection, the standard "Snowmass Year" factor should be increased by 30%. With continuous injection, the operation of this accelerator will be qualitatively different from present colliders.

The next generation asymmetric B Factory will operate mainly at the $\Upsilon(4S)$with

		Hadron Collider Experiments			e^+e^- B Factories	
Decay Mode	Branching Fractions	**CDF** **D0** (2 fb^{-1})	**BTeV†** **LHCb** (10^7 s)	**ATLAS** **CMS** (1 Year)	**BABAR** **BELLE** (0.5 ab^{-1})	**10^{36}** (10 ab^{-1})
$B \to X_s\gamma$	$(3.3 \pm 0.3) \times 10^{-4}$				11K	220K
					1.7K (B Tagged)	34K (B Tagged)
$B \to K^*\gamma$	5×10^{-5}	170	25K		6K	120K
$B \to \rho(\omega)\gamma$	2×10^{-6}				300	6K
$B \to X_s\mu^+\mu^-$	$(6.0 \pm 1.5) \times 10^{-6}$		3.6K		300	6K
$B \to X_s e^+e^-$					350	7K
$B \to K^*\mu^+\mu^-$	$(2 \pm 1) \times 10^{-6}$	60-150	2.2K/4.5K	665/4.2K	120	2.4K
$B \to K^* e^+e^-$					150	3K
$B \to X_s\nu\overline{\nu}$	$(4.1 \pm 0.9) \times 10^{-5}$				8	160
$B \to K^*\nu\overline{\nu}$	5×10^{-6}				1.5	30
$B_d^0 \to \tau^+\tau^-$	10^{-7}					
$B_s^0 \to \mu^+\mu^-$	10^{-9}	5/1.5-6	5/11	9/7		
$B_d^0 \to \mu^+\mu^-$	8×10^{-11}	0/0	1/2	0.7/20		
$B \to \tau\nu$	5×10^{-5}				17	350
$B \to \mu\nu$	1.6×10^{-7}				8	150
$B^0 \to \gamma\gamma$	10^{-8}				0.4	8

†Two armed version of BTeV

Table 2: Reconstructed rare B decays in hadronic and e^+e^- experiments

a center-of-mass energy of 10.58 GeV, with an energy asymmetry a bit smaller than currently used; a period of operation at the $\Upsilon(5S)$ may also be desirable. For the present study the PEP-II tunnel geometry was used, with beam energies of 7.47 and 3.73 GeV, as a reduced energy asymmetry considerably reduces RF costs and power consumption. To increase the luminosity about two orders of magnitude the beam currents must be raised an order of magnitude and the beam cross sectional area reduced an order of magnitude while keeping the beam-beam tune shifts under control. The parameters shown in Table 3 are self-consistent but further optimization is certainly possible [6].

The observed beam-beam tune shifts in PEP-II now approach 0.07. The expected tune shifts in this new accelerator could be larger. It has been observed in PEP-II that by adjusting the tunes the luminosity can be increased significantly 10% at the expense of the beam lifetime. (This beam lifetime will be called the beam-beam lifetime.) Higher luminosity for the same current means higher tune shifts. The new accelerator can take advantage of continuous injection to push the tune shifts to significantly higher values and consequently the beam-beam lifetimes to significantly lower values. The beam-beam lifetime in present colliders is about 100 minutes. The design assumption is that the tune shifts can be increased from 0.07 to at least 0.10 by reducing the beam-beam lifetime from 100 minutes to ~5 minutes.

The interaction region will likely have a geometry that combines the best features of the PEP-II and KEK-B designs [7]. The cone angle separating the accelerator and

	SuperHER	**SuperLER**
Beam energy (GeV)	7.47	3.73
Beam current (A)	11	22
Number of bunches	7000	
Bunch length	1.7	
Beam lifetime τ_b (min)	5	3
$\beta^*(x/y)$ (mm)	15	1.5
Emittance (x/y) (nm)	44	0.44
Beam size at IP (x/y) (μm)	81	0.8
Beam-beam tune shifts	0.10	
RF frequency (MHz)	956	
Luminosity ($\mathrm{cm}^{-2}\mathrm{s}^{-1}$)	10^{36}	

Table 3: Parameter list for a 10^{36} collider in the PEP-II tunnel at SLAC.

detector components can be about 300 mrad, as at present. The LER quadrupoles for this accelerator can be moved significantly closer to the IP than in PEP-II using superconducting Q1 and Q2 magnets with stronger gradients, such as those used in the HERA upgrade [8]. The HER quadrupoles can also be moved closer because the LER quadrupoles have been moved. A crossing angle of about 1.5 mrad is used to help separate the beams at the first parasitic beam-beam crossing. The beams are horizontally separated by about 12 σ_x at the first parasitic crossing.

The HER vacuum system must dissipate over 16 kW/m of synchrotron radiation power. The chambers will likely be made with an antechamber with a continuous built-in photon stop. The design of bellows (expansion) modules would be very difficult for these high currents and short bunch lengths. Instead, the plan is to use a concept investigated for the PEP-II rings but not implemented. The vacuum system would be a continuous extrusion welded together with no bellows but with rigid supports to constrain thermal stresses. A similar technique is used to build very long welded railroad tracks. The beam impedance will improve without bellows. The stainless steel chambers in the straight sections will have to be changed to a lower resistance material to reduce the resistive wall effect for the LER.

Injection must be a continuous process because the beam lifetimes are short. Taking the SLAC site, the beams would come from the damping ring and linac complex. The SLAC system was built to provide about 1×10^{11} electrons per pulse at 120 Hz and about half that rate for positrons. The damping ring cavity RF frequency will be changed from 714 MHz to 476 MHz. In the damping rings, the particle bunches will be distributed uniformly over about half the circumference (35 m) in about 30 bunches. The other half of the ring circumference is used by the injection and extraction kicker rise times. The linac can operate at 120 Hz. The electron injection rate

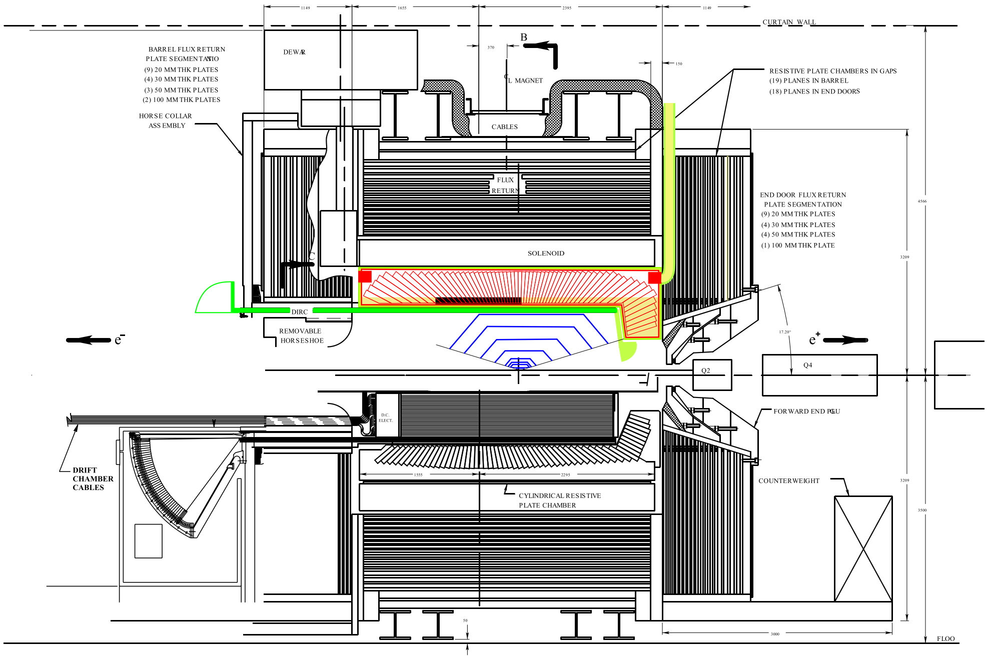

Figure 1: Elevation view of an upgraded *BABAR* detector designed for a 10^{36} collider. The upper half shows the new components, the lower half, the existing detector.

would likely be 80 Hz, the positron injection rate 20 Hz and the remaining 20 Hz used for positron production. Injection losses can cause detector problems. However, the damped injected beam will have transverse emittances smaller than the stored beam emittances. The linac bunch length and energy spread are well matched to the stored bunches, promising a relatively clean injection process. As some injection collimation will likely be needed, however, the injection efficiencies were assumed to be 75%.

4 Super*BABAR*

Doing a precision experiment at a 10^{36} asymmetric B Factory requires a new or upgraded detector to cope with backgrounds and radiation levels. Studies at Snowmass indicate that this is a tractable problem. There appears to be a feasible upgrade path from the existing *BABAR* detector, which is sketched in Fig. 1. This approach would retain the existing 1.5 T superconducting solenoid and flux return, as well as the instrumented flux return detectors, which will be upgraded over the next several years. The electromagnetic calorimeter would be based on scintillation light from liquid xenon, the vertex measurement and tracking would be done by a combination of two pixel detector layers and approximately seven double-sided silicon strip layers. The DIRC particle identification system would be rebuilt to do away with the large water-filled stand-off box, which is a large source of background. R&D efforts on liquid xenon scintillation calorimetry and on a new readout scheme for the DIRC are getting underway.

A straightforward extension of the open trigger approach traditionally employed in experiments appears to be quite practical. Techniques for detector readout pioneered for the new generation of experiments at the Tevatron and LHC appear to be generally applicable to a 10^{36} storage ring, allowing unbiased triggering on essentially all events of interest.

5 Conclusion

In summary, the physics case for a 10^{36} asymmetric B Factory is quite strong. The program has many unique aspects and is complementary to the programs at hadronic machines. The details of machine and detector design are far from mature, but both machine and detector appear to present reasonable challenges. Undoubtedly, developments in both theory and experiment over the next several years will sharpen our vision and allow a clearer determination of the importance of pushing flavor physics investigations to this new level in rare decays and precision measurements.

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