STATUS OF B FACTORIES AND DETECTORS

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In this paper is given an overview of the status of the two asymmetric e^+e^- B Factories PEP-II and KEKB, that will begin operation in Spring 1999, as well as the status of the two detectors *BABAR* and Belle that will operate at these machines.

1 Physics Goals of the Next Generation of B Factories at the $\Upsilon(4S)$

The principal goal of asymmetric B Factories at the $\Upsilon(4S)$ is the comprehensive study of CP violation in the system of the B mesons [1]. The asymmetry in the beam energies makes possible the measurement of time dependent CP violating asymmetries in the decay of neutral B mesons.

The CP violating asymmetries in the B meson system are quite large, so that only relatively small samples of events are needed to provide accurate measurements. Unfortunately, the B meson decay channels relevant for the study of CP violation have extremely small branching fractions, of the order of 10^{-4} or below. Therefore, in order to measure asymmetries with errors at the 10% level or better, samples of more than 10^7 neutral B meson pairs need to be produced.

The measurement of CP violation in the B system can be pursued at hadronic machines as well. For instance, the CDF Collaboration has recently published evidence for large time dependent CP asymmetries [2] in the channel $B^o \to J/\Psi K^o_S$, taking advantage of the very large B production cross section at the TEVATRON. At e^+e^- facilities, the B cross sections are much smaller. The main advantage of an experiment at the $\Upsilon(4S)$ is to be found in the large signal to noise ratio and the relatively clean environment, making possible the study of a wide range of decays, including decays with neutral pions, and allowing for sophisticated particle identification techniques.

The $\Upsilon(4S)$ resonance decays always into a pair of B mesons, about half of them being neutral. The B mesons are produced in a coherent $L = 1$ state and almost at rest in the $\Upsilon(4S)$ frame. The coherent system evolves until one of the two B^o mesons decays. The second B^o continues its evolution and decays eventually. If one of the two mesons decays into a channel of interest, for instance $B^o \to J/\Psi K^o_S$ or $B^o \to \pi^+\pi^-$, the event is classified according to the flavour of the other B meson at decay. The latter is determined with some confidence using flavour tagging techniques, based for instance on the charge of leptons and/or kaons in the decay products. Thanks to the energy asymmetry of the beams, the $\Upsilon(4S)$ is given a boost at production in the laboratory frame. The measurement of the time difference between the two B mesons decays is deduced from the distance between the two decay vertices along the boost axis.

The amplitudes of time dependent asymmetries can be interpreted in terms of angles of the Unitarity Triangle. These interpretations are in some cases subject to theoretical uncertainties, however.

Promising channels for the measurement of $\sin 2\beta$ are $B^o \to J/\Psi\ K_S^o$ and $B^o \to J/\Psi\ K_L^o$, as well as other decays involving a charmonium state. The extraction of $\sin 2\beta$ in these channels is clean theoretically. There are many other channels that can contribute significantly to the measure, such as $B^o \to D^+ D^-$, $B^o \to D^{\star +} D^{\star -}$ etc.

The key to the measurement of $\sin 2\alpha$ is the study of charmless hadronic decay channels an example of which is $B^o \to \pi^+\pi^-$. The extraction of $\sin 2\alpha$ is complicated by the unknown amplitude of penguin contributions to these decays. The best hope for a clean measurement turns out to be in the channel $B^o \to \pi^+\pi^-\pi^o$, where all the information, including the value of α, can be deduced, at least in principle, from the study of the interference pattern in the Dalitz plot. Due to a small branching fraction and a relatively large background level for the $\pi^+\pi^-\pi^o$ mode, several years of data taking will probably be needed to achieve this goal.

In addition, a rich program of physics at the $\Upsilon(4S)$ will benefit from the unprecedented high luminosity of the new e^+e^- B Factories, an order of magnitude higher than existing machines. This includes improved measurements of V_{ub} and V_{cb}, studies of rare B decays, search for non-standard decays, and the usual charm, τ and $\gamma\gamma$ physics. Direct CP violation will be looked for in the decays of charged B mesons. Most of this physics does not require any particular beam asymmetry, and will be pursued at Cornell with the CLEO-3 detector as well.

2 The PEP-II and KEKB B Factories

The new generation B Factories are aiming at luminosities of order 10^{33} to 10^{34} cm^{-2}s^{-1}. Amongst the parameters that can be pushed to achieve this goal are the total current I and the beta function or focusing strength $\beta^\star$ at the interaction point [3].

The strategy to obtain high currents while keeping the single bunch current reasonably low is to increase the number of bunches. The asymmetric B Factories have very large number of bunches (1658 in the case of PEP-II, 5000 in the case of KEKB.) The maximum number of bunches is determined by the design of the interaction region and the way the two beams are separated after crossing. The ways the two B Factories accomplish their beam separation are quite different.

In the case of KEKB, the two beams collide with a non-zero crossing angle (± 11 mrad.) This option allows a very short bunch spacing of 60 cm, hence a larger number of bunches. The danger of this technique is the possibility of synchro-betatron oscillation that could limit the ultimate luminosity. The so-called crab-crossing technique, which consist in tilting the bunches in such a way that they collide head-on while still crossing with an angle, is under investigation in case the instabilities turn out to be a limiting factor for reaching the maximum luminosity.

In the case of PEP-II, the two beams are separated by the means of strong permanent dipole magnets placed very close to the interaction point, the beams colliding head-on with a bunch spacing of 1.26 m. A drawback of this design is a potentially large background due to synchrotron radiation. It had also a significant

Table 1. Main parameters of the PEP-II and KEKB machines.

	PEP-II		**KEKB**	
	LER e^+	HER e^-	LER e^+	HER e^-
E (GeV)	3.1	9	3.5	8
β_y (cm)	1.5	2	1.0	1.0
I (A)	2.1	1.0	2.6	1.1
Circumference (m)	2219 (PEP)		3016 (TRISTAN)	
Bunches	1658		5000	
Bunch Spacing (m)	1.26		0.60	
$\Delta\nu$	0.03		0.05	
Crossing Angle (mrad)	0 (head-on)		± 11	
L (cm^{-2}s^{-1})	3.10^{33}		10^{34}	

impact on the design of the *BaBar* experiment inner detectors.

The main parameters of the two machines are given in Table 1. The larger expected value of the luminosity at peak for KEKB, results from a complex combination of many factors, including beam intensities, focusing power at the interaction point and the tune shift limit parameter $\Delta\nu$.

Assuming a peak luminosity of 3.10^{33} cm^{-2}s^{-1}, and an excellent operational efficiency, one expects to reach an integrated luminosity of 30 fm^{-1} per nominal year of data taking, which corresponds to a sample of about 15 million B^o pairs.

3 The *BaBar* and Belle Detectors

The detectors for the physics of CP violation at asymmetric B Factories must have good capabilities in three main areas:

- Spectroscopy. The exclusive reconstruction of a wide range of B decay channels, with small branching fractions and hence high potential backgounds, requires excellent momentum and energy resolution, good acceptance in particular in the forward region, good track reconstruction efficiency down to transverse momenta of order 50 MeV/c, excellent π^o and γ detection efficiency and some K_L^o detection capability. Particle identification, required for distinguishing kaons from pions in two-body B decays, must be excellent up to momenta as high as 4 GeV/c in the forward region, due to the boost.

- Flavor Tagging. Mostly based on the charges of leptons and kaons, flavor tagging, a key point of the measurement of time dependent CP asymmetries, requires both lepton identification down to as small momenta as possible, and kaon identification below 2 GeV/c.

- Vertexing. The vertex position resolution along the boost axis must be small compared to the average distance between the two B vertices, which is of the order of 250 μm at PEP-II and KEKB. This resolution turns out to be limited by multiple scattering in the beam pipe.

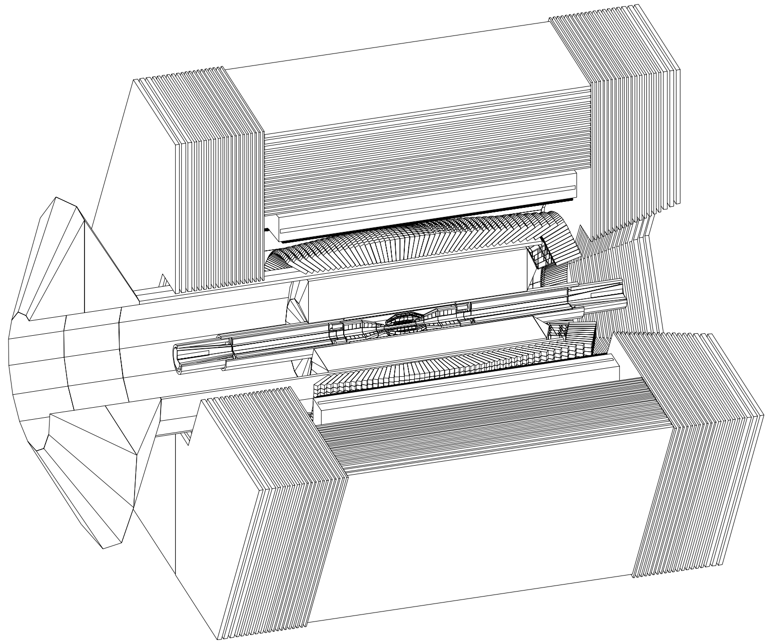

Figure 1. Layout of the *BABAR* detector.

The designs of the two experiments to meet these requirements are rather similar [4 5]. Both experiments have a 1.5 T superconducting solenoidal magnet, a silicon vertex detector, a central drift chamber, an electromagnetic calorimeter made of Cesium Iodide crystals, an instrumented flux return for the detection of muons and K_L^0, and a dedicated charged hadron identification system. This is summarized in Table 2.

The main differences between the two experiments are the radiation hardness of *BABAR*'s silicon tracker, a larger volume for Belle's central detector, a larger internal radius for Belle's calorimeter, and different techniques for particle identification: for Belle, a combination of time of flight (for tagging) and aerogel; for *BABAR* a novel ring imaging Čerenkov detector, the DIRC.

4 Status of PEP-II and KEKB at the End of Year 1998

The commissioning of KEKB's High Energy Ring (HER) started on December 8, 1998. By the end of the month, they had already obtained an impressive list of achievements: they were able to store 19 mA in the ring using 60 bunches. They reached a single bunch current of 1.5 mA, for a designed value of 0.22 mA. The injection rate was 5 Hz, only a factor of 10 below the design value. The x, y and z-tunes, and the value of the $\beta^\star$ function at the interaction point, were measured close to design values.

At the time of this Conference, the commissioning of KEKB's Low Energy Ring

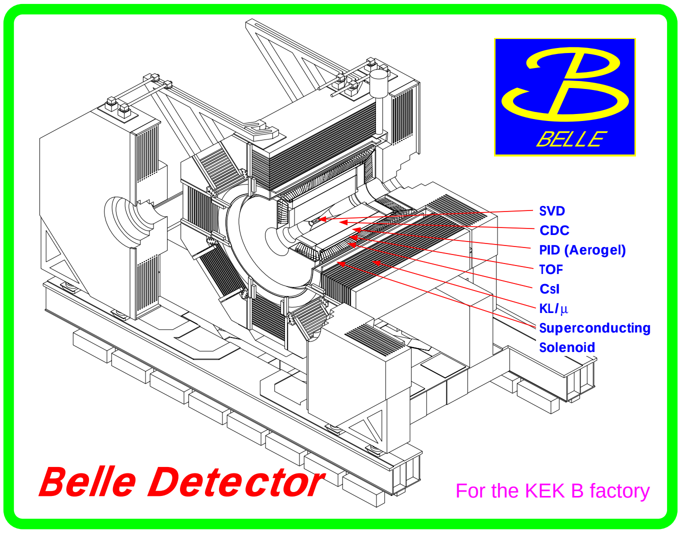

Figure 2. Layout of the BELLE detector.

Table 2. Detectors for *BABAR* and Belle.

	BaBar	**Belle**
Super Conducting Magnet	1.5 T	1.5 T
Silicon Vertex Detector	5 layers radiation hard lampshade	2X2 layers radiation soft
Central Drift Chamber	25-79 cm 40 layers	8-87 cm 50 layers
Particle Identification	DIRC	TOF+Aerogel
Electromagnetic Calorimeter	CsI Xtals no end-cap	CsI Xtals
μ/K_L^o Detector	Steel/RPC	Steel/RPC

(LER) had not started yet, due to a minor problem in the cooling system of the dipole magnets. The 3.5 GeV positron beam was successfully brought to the end of the transport line, though.

In the case of PEP-II, the strategy was to commission the HER one year before the LER, whose operation began early Summer 98. By the end of December 98, PEP-II had reached a current of 309 mA in the LER, and 273 mA in the HER. The

Collaboration was able to collide the two beams, 260 bunches in each beam, with a total 260 mA in the LER and 84 mA in the HER. It measured a luminosity of $8.8\ 10^{31}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$, as determined from beam size and current measurements, and also checked that the luminosity was scaling linearly with the number of bunches.

5 Machine Backgrounds

For both KEKB and PEP-II, dedicated background detectors have been located around the interaction region in order to estimate the impact of backgounds on the detector operation before their installation.

At the time of the Conference, the first results from KEKB background studies with their Beast detectors, were not available yet.

In the case of PEP-II, the background detectors were used over the past year to study the backgrounds from both beams and to predict the radiation levels expected when *BaBar* is in place. Various background reduction techniques were tried including trajectory steering in the interaction region, energy and betatron collimators, and vacuum pressure changes in the interaction region and the ring arcs.

Very schematically, the conclusions of the studies on the PEP-II HER are that the synchrotron radiation is consistent with expectations, and that the lost-particle background is consistent, within a factor of two, with beam-gas scattering. The background rates however, if now rather well understood, are much higher than previous estimates: extapolated to the nominal 1 A current, HER backgrounds are estimated to be a factor 7 to 10 higher than *BaBar* Technical Design Report predictions. Preliminary results show that the LER backgrounds are dominated by high dynamic pressure.

The first action to take is of course to improve the vacuum in the HER and LER. Scrubbing of both rings is in progress. A second action was to add more collimators, whose purpose is to reduce the effect of Coulomb scattering and bremsstrahlung induced backgrounds. Finally, the *BaBar* Collaboration is taking measures for its 1999 run to cope with larger than expected background levels.

In summary, the backgrounds are higher than expected but low enough so that *BaBar* can start data taking after an initial beam scrubbing period.

6 Readiness of the Two Detectors

The Belle Detector is completed (though there are plans for the replacement of the silicon vertex detector by a radiation hard version later on.) System tests with cosmic rays are in progress, and will continue until the end of February 99. The Belle Detector roll-on will start early March 99 and by April 10, 1999, Belle will be ready for data taking.

The *BaBar* Detector is essentially completed, except for the DIRC quartz bars (Čerenkov radiator), because of problems related to polishing procedure. Only five out of twelve quartz bar sectors, one of which is a spare, will be present at start up. The cosmic rays system test will continue until the end of January 99. The detector roll-on will start on March 16, and *BaBar* will be ready for data taking by

April 22, 1999.

7 Tentative Schedule for the First Year of Data Taking

For both machines, the primary goal is to provide the detectors with a luminosity of 10^{33} cm^{-2}s^{-1} or higher, with acceptable background levels and good reliability, for the physics runs starting by the Fall of 1999. The period between the first recorded collisions in the detectors, by May-June 99, and the end of the Summer 99, known as the First Year of Data Taking, will be devoted mostly to engineering physics for the understanding of *BaBar* and Belle detectors.

Precise schedules are not established yet. A possible scenario would be to run in May-June 99 for one week at relatively low luminosity, of order 5 10^{31} cm^{-2}s^{-1}, providing the detectors with of order 100,000 hadronic events with reasonably good conditions of background, for their preliminary detector studies. Then, a scan of the $\Upsilon(4S)$ and $\Upsilon(3S)$ resonances would be performed, in order to find the optimal running conditions and the absolute energy scale of the machines. Owing the necessary periods of machine development and the periods of scrubbing, one can estimate that the machines will raise the luminosity to 10^{33} cm^{-2}s^{-1} and low levels of backgrounds by the end of July 99. That would leave about two monthes of data taking for the detectors with an average peak luminosity of about 5 10^{32} cm^{-2}s^{-1}, and an estimated integrated luminosity by the end of the run period of the order of 1 fm^{-1}, constituting enough data for fine detector tuning.

8 Conclusion

Despite very aggressive schedules, the two projects of asymmetric B Factories at PEP-II and KEKB, and the *BaBar* and Belle detectors, are ready for first collisions in May 99.

One of the main concerns remains the high level of machine backgrounds as measured during the commissioning of PEP-II rings. High backgrounds could be a limiting factor to the ultimate luminosity, and considerable effort is devoted to bring them to a level that detectors and physics can bear.

At the end of the Summer of 99, *BaBar* and Belle will have recorded sufficient amount of data for detector tuning and engineering studies, and will be ready to attack in October 99 their ultimate goal, B physics and the understanding of the CP violation puzzle in the Standard Model.

Acknowledgments

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