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Introduction

In the thirty years that have elapsed since the surprising discovery of *CP* violation in K^0_L meson decay, the Standard Model of elementary particle physics has evolved considerably. The Standard Model with three quark generations accommodates *CP* violation in quark decays in an elegant and economical manner. Through one imaginary parameter and three real numbers, the Standard Model completely characterizes the weak couplings of the six quarks as expressed in the Cabibbo-Kobayashi-Maskawa matrix. We have little evidence, however, that this explanation is correct.

Indeed, there are hints from cosmological arguments that, in fact, it is not. *CP* violation is a key piece in the puzzle of the matter dominance in the universe. The excess of matter over antimatter is not an easily explained property of the universe. In any theory with baryon-number-violating processes (for example, most grand unified theories) the universe at very early times contains equal (thermal) populations of quarks and antiquarks. How and when the currently observed imbalance develops is one of the key puzzles of cosmology. Attempts to explain this with only Standard Model *CP* violation have so far not been successful, leading to the suggestion that perhaps *CP* violation physics is the Achilles heel of the Standard Model. Certainly it merits detailed exploration.

The study of *CP*-violating asymmetries in the decays of B^0 mesons to *CP* eigenstates promises, at last, to provide a test of the Standard Model explanation of *CP* violation. More generally, the measurement of these *CP* asymmetries can provide us with a series of unique, and uniquely stringent, consistency tests of the quark sector of the Standard Model. These tests, which will be carried out by the BaBar detector at PEP-II, will provide us with perhaps the best chance to challenge the Standard Model in new and quantitatively precise ways. This challenge has come about through the interplay of a series of experimental and theoretical events.

While it had been understood for several years that the measurement of *CP*-violating asymmetries in B^0 decay could lead to important tests of the CKM matrix [Car81], the experiments seemed beyond reach. The discovery of a surprisingly long b-quark lifetime by MAC [Fer83] and Mark II [Loc83] at PEP in 1983, together with an unexpectedly large B^0-$\overline{B}^0$ mixing by UA1 [Alb87b] and ARGUS [Alb87a] in 1987 made it possible to contemplate making these measurements. It soon became clear [SNO89] that the richest and most straightforward approach involved experiments at a variety of e^+e^- machines, either in the $\Upsilon(4S)$ region, in the PEP/PETRA continuum region, or at the Z^0 pole. Experiments at hadron machines can also address this physics. While hadronic experiments potentially have larger samples of B mesons, they face substantial trigger and combinatoric problems [HER94]. The most favorable e^+e^- experimental situation, that is, the one producing the smallest statistical error with the least integrated luminosity, is the asymmetric storage ring first proposed by Oddone [Odd87]. This machine would boost the decaying B^0 mesons in the laboratory frame, allowing existing vertex measuring technology to measure the time order of $B^0 - \bar{B}^0$ decay pairs, even with the short B meson flight distance. This, however, would require event samples that are obtainable only with significant advances in storage ring luminosity.

PEP-II promises to provide the required luminosity [SLA91], initially $3 \times 10^{33}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$, ultimately 10^{34}, with asymmetric Υ(4S) production at a $\beta\gamma$ of 0.56 (9 GeV electrons on 3.1 GeV positrons). The $B\overline{B}$production rate will be 3 Hzat the initial luminosity, ultimately rising to 10 Hz. The experimental challenge is then to provide high efficiency, high resolution exclusive state reconstruction in a situation new to the e^+e^- world: a center-of-mass in motion in the laboratory. The boost is not extreme: at PEP-II, 90° in the center-of-mass is at 65° in the laboratory. Nonetheless, the challenges this boost poses for the detector are novel, and not easily met.

The measurement of *CP*-violating asymmetries in B^0 meson decay will be a major breakthrough. It will, however, be only the first installment in a rich program that will ultimately provide us with very stringent tests of the Standard Model. The key to these tests is the measurement of the *unitarity triangle* relations between the CKM matrix elements. The ultimate precision of the unitarity triangle tests depends not only on the *CP*-violating asymmetries, which measure the angles of the unitarity triangle, but on improved measurements of the triangle sides as well. The series of measurements that is uniquely possible at an asymmetric e^+e^- storage ring operated at the $\Upsilon(4S)$ resonance will both measure the angles for the first time and substantially improve the measurement of the triangle sides. They will, further, provide unique tests of underlying theoretical assumptions and measurements of experimental systematic uncertainties. Should discrepancies with Standard Model predictions emerge, the program can also pinpoint particular extensions of the Standard Model, be they supersymmetry, left-right models, or other specific models.

While the search for *CP* violation and for possible contradictions with the Standard Model CKM picture of its origin is the most exciting physics challenge for *BaBar*, it is by no means the only physics opportunity to be exploited. The asymmetric configuration and the resultant separation of B vertices makes possible searches for rare B decays, such as $b \to u$ transitions, in a very clean environment. The large production rate for charm, either directly in continuum $c\bar{c}$ events or indirectly from B decays, provides opportunities for charm physics. Similarly, aspects of tau physics can readily be studied here with large data samples in a clean environment. These opportunities are discussed in some greater detail in Chapter 3.

A detector designed to carry out this ambitious experimental program must be capable of high efficiency reconstruction of extremely rare exclusive final states in the presence of combinatoric and accelerator-generated backgrounds. This requirement places a premium on solid angle coverage, charged particle momentum resolution and species identification, and photon resolution and detection efficiency. The design of the *BaBar* detector attempts to balance these requirements against one another and against cost and schedule imperatives.

Soon after the approval of PEP-II in October of 1993, efforts began to form a major international collaboration to build and operate a new detector at PEP-II's single interaction region. Time to build a detector is short, and there has been a clear convergence of thinking [SLA93, BEL94, HEL92] about new detector designs. The SLAC directorate, with the approval of the Scientific Policy Committee, invited a group of experimentalists to submit a Letter of Intent and a Technical Design Report. The primary aim of this group is the detailed study of CP-violating asymmetries in B^0 meson decay, with a wide variety of other B, charm, τ, and two-photon physics that will also be accessible at new levels of precision. An inaugural meeting was held in December of 1993. The Collaboration drafted a governance document, chose a name and its leadership, and entered into the detailed design of the *BaBar* detector.

A detailed *Letter of Intent* [Bab94] was submitted to the SLAC Experimental Advisory Committee (EPAC) in June of 1994. The EPAC recommended that the *BaBar* Collaboration be approved to proceed to a Technical Design Report (TDR). This recommendation was accepted by the SLAC Director, who asked for a TDR by the end of 1994. This document is that report.

The detector described in the *Letter of Intent* was a conceptual design, which in some instances contained alternative technology choices for several detector subsystems. The design discussed herein is substantially more detailed. It contains specific choices for the subsystem technologies, and the design of these subsystems has been optimized to provide a balance between cost and adequate physics performance.

The planning of the PEP-II project has been done in sufficient detail that the Laboratory is confident that it can be constructed in five years, starting in October of 1993. In designing *BaBar*, we have taken as an important constraint that a detector capable of measuring CP-violating asymmetries in B^0 meson decay be operational on a timescale matched to that for building PEP-II.

The *BaBar* Collaboration management team is functioning, with a Spokesman, Deputy Spokesman, Technical Coordinator, and a Project Engineer. System managers are in place, as well. Should the EPAC recommend approval on the basis of this document, the TDR, together with a detailed Work Breakdown Structure, cost estimate, critical path schedule, and Management Plan, will be submitted for approval by the DOE and the funding agencies of the non-US institutions. With the establishment of Memoranda of Understanding (MOUs) detailing the specific responsibilities of each collaborating group, the construction of the *BaBar* detector will commence in earnest.

The following Chapter describes the proposed detector, discusses some of the design decisions and their physics basis and reviews the performance expected component by component. Chapter 3 presents a physics overview, including results of simulation studies for the key *CP* violation study channels as well as an overview of other physics opportunities. Detailed descriptions of each detector subsystem are then provided in individual chapters. Finally there are chapters that summarize general detector issues, such as accelerator-induced backgrounds, safety, installation and integration, management, budget and schedule.

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