Princeton University
DOE/ER/3072-45
June 20, 1988

Status Report of the Fermilab B Collider Study Group[1]

Participating Institutions[2]

U. of California (Davis), Fermilab, U. of Florida, Illinois Institute of Tech., U. of Iowa, Northeastern U., Ohio State U., U. of Oklahoma, U. of Pennsylvania, Princeton U., and Yale U.

Abstract

The motivation, size and scope of a B-$\bar{B}$ CP-violation experiment, called here the Bottom Collider Detector, at an upgraded Tevatron Collider is indicated. Preliminary results from detector and event simulation studies by the Bottom Collider Study Group are presented. No detector design details are discussed though some overviews are given. Where appropriate, discussions on what further study is required is given. The need for an upgraded Tevatron is absolutely clear. A factor of 200 increase over the present design luminosity of 1×10^{30} cm^{-2}sec^{-1}is highly desirable. This report is not intended as a proposal nor as a finished study but merely represents the status of our thinking at this time: the Bottom Collider Detector is challenging but doable; it is the most agressive pursuit of CP-violation physics possible in the near future, and would be a vital step in the development of the high-rate, 4π instrumentation needed for the SSC era.

Introduction

The goal of the Bottom Collider Detector is to produce 10^{11} B-$\bar{B}$ events for which an efficient single-lepton trigger tags one B and permits detailed study of the few-particle decay modes of the other B. The trigger efficiency should be at least 5%, and the combined acceptance and vertex reconstruction efficiency for the other B should be above 20%, so that a sample of 100,000 reconstructed events would be obtained for a mode with a 10^{-4} branching fraction. A sample of this size in each of several few-body decay channels will permit a detailed study of CP nonconservation in the B-$\bar{B}$ system. A decay mode with a 10^{-8} branching fraction would still yield 10 events, so the study of rare processes is an obvious byproduct.

The very large B-$\bar{B}$ cross section at 2 TeV (~ 45 μb),[3] the relatively favorable ratio of bottom to total cross section ($\sim 10^{-3}$), combined with an average luminosity of 10^{32} cm^{-2}sec^{-1}makes the upgraded Tevatron Collider a unique B facility that will produce important and fundamental physics results on a time scale of approximately 5 years from now.

Similar ambitious physics goals are being considered in the e^+e^- community; the B-$\bar{B}$ cross section at the $\Upsilon(4S)$ is about 1 nb, while the trigger efficiency might be close to 100%. No credible plan exists for a new e^+e^- machine that could reach the luminosity of 10^{34} cm^{-2}sec^{-1}with asymmetric beam energies as needed to compete with the hadron-collider option.

The Bottom Collider Study Group was formed to follow up on ideas developed at the Workshop on High Sensitivity Beauty Physics at Fermilab, Nov. 1987, which in turn was prompted by two letters of intent submitted to Fermilab for consideration in 1987.[4,5] The group has taken a very broad and ambitious approach to defining the experimental goals and parameters associated with performing a high-statistics B experiment in the upgraded Tevatron collider. The organization set up for studying the issues was to divide the study group into several sections, each addressing one aspect of the experimental design, and then meeting roughly once a month to present the work to date.

The starting design parameters used as guidelines are listed below:

- pp or $\bar{p}p$ collisions at $\sqrt{s} = 2$ TeV;
- An average luminosity of about 10^{32} cm^{-2}sec^{-1};
- Interaction rate of 5 MHz ($\sigma_t = 50$ mb);
- $\sigma_{BB} = 45$ μb, or 4500 B-$\bar{B}$ events/sec;
- An average event multiplicity of 60 charged pions and 30 π^0's;
- A magnetic detector with acceptance from $2°$ to $178°$, or roughly ± 4 units of rapidity;
- A semileptonic trigger efficient for electrons of 1 GeV/c P_T and above;

- At a hadron collider the B-decay modes useful for study of CP violation are those which permit reconstruction of the B mass;
- Charged tracks from B decay are fully reconstructed including a μ-vertex measurement and particle identification;
- A B-mass resolution of 25 MeV/c^2 is needed to suppress combinatoric backgrounds, and to separate B_d from B_s;
- Only B-decay modes containing all charged tracks will be reconstructed; π^0 reconstruction is not required;
- An hermetic hadron calorimeter is not required as missing-E_T is not an important quantity for B-$\bar{B}$ physics.

The main issues are discussed in the following sections:

1. Bottom Physics Goals

The major physics goal of this experiment is to observe and study CP nonconservation in the neutral and charged bottom-meson systems. The B-$\bar{B}$ system provides a detailed test of the standard model in that the parameters of the K-M matrix may be overdetermined by measurement of CP violation in several different modes. The opportunity for systematic study is much greater than in the K-$\bar{K}$ or D-$\bar{D}$ systems, with the corresponding prospect for greatly increased understanding of the quark mass matrix. Deviations from present expectations would give important clues about the Higgs sector and possible new generations of quarks. Exploration of the B-$\bar{B}$ system is vital for a better understanding of the sources of CP violation beyond the parametrization that we have now.[6]

The proposed experiment is concerned with the systematic investigation of CP violation in several channels of B-$\bar{B}$ decay, rather than merely providing low-statistics evidence that CP violation exists. The technique which appears of most general utility in a collider experiment is a search for asymmetries of the type

$$A = \frac{\Gamma(B \to f) - \Gamma(\bar{B} \to \bar{f})}{\Gamma(B \to f) + \Gamma(\bar{B} \to \bar{f})}.$$

When final state f is the same as $\bar{f}$, as in many potentially favorable cases, the decaying B must be identified as a B or $\bar{B}$ (which is complicated in an interesting manner by bottom oscillations). This identification is made by determining the flavor of the other B of the B-$\bar{B}$ pair. In a hadron-collider experiment this is necessary anyway for trigger purposes, in that the sign of the electron in the triggering decay $B \to eX$ identifies the flavor. Decay modes of the B^0 such as $D^+\pi^-$ are 'self tagging' and would not require a trigger on the other B. Likewise, analysis of asymmetries of charged-B decays does not require flavor identification of the other B. While these modes will be explored in the Bottom Collider Detector we are unlikely to profit from the freedom to ignore the second B.

We would concentrate on few-particle final states f such as $\pi^+\pi^-$, K^+K^-, $p\bar{p}$, $D^+\pi^-$, ψK_S, $\psi\pi^+\pi^-$, *etc.*, which yield only charged particles in the detector. Estimates of the asymmetry parameter A for such decays are of order 0.1, while the branching fractions are expected to lie in the range 10^{-4}-10^{-5}.

To reach a statistical significance of S standard deviations in a measurement of asymmetry A the total number N of tagged and reconstructed decays required is

$$N = \left(\frac{1}{A^2} - 1\right) S^2 \sim \frac{S^2}{A^2}.$$

Thus a 5σ signal requires $N = 2500$ for $A = 0.1$, but $N = 250,000$ for $A = 0.01$. Clearly the experiment must have the flexibility to profit from those decay modes with $A \sim 0.1$, but it is not known at present which modes these are.

It may well be a tradeoff of Nature that modes with large asymmetries, A, have small branching fractions. If we then take 10^{-5} as the more likely branching fraction for the interesting modes with $A \sim 0.1$, we would need 2.5×10^8 tagged B's for a significant study.

Supposing the tagging efficiency (times reconstruction efficiency) can be maintained at 1% in the hadron-collider environment, a total of 2.5×10^{10} B-$\bar{B}$ pairs is required for a serious investigation. This sets the scale of effort required in the proposed experiment.