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B-Physics Prospects at CDF

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Abstract

Between 1992 to 1996, the CDF experiment has collected a data sample of 110 pb^{-1} of $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV at the Fermilab Tevatron. In the year 2001 the Tevatron will commence $p\bar{p}$ collisions again at $\sqrt{s} = 2.0$ TeV delivering an integrated luminosity of 1 fb^{-1} per year. In the mean time the CDF detector will have undergone substantial upgrades which will allow for a rich B physics program with unique capabilities. In this paper we discuss the B physics prospects at CDF with the data that will be collected during this upcoming Tevatron run.

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1 Introduction

In this paper we discuss the B physics prospects at CDF (Collider Detector at Fermilab), at the Fermilab Tevatron. From August 1992 to February 1996, the CDF detector collected a data sample of 110 pb^{-1} of $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV and we refer to this period as Run I. The Tevatron will commence $p\bar{p}$ collisions again at $\sqrt{s} = 2.0$ TeV in the Spring of 2001 with an initial goal of delivering an integrated luminosity of 1 fb^{-1} per year, corresponding to approximately 10^{11} $b\bar{b}$ pairs produced per year. This upcoming data taking period is referred to as Run II. The first phase of Run II is expected to last two years yielding a data sample of 2 fb^{-1}. Although ultimately a data sample of more than 15 fb^{-1} will be probably collected before the turn-on of the LHC, we base the expectations discussed in the following sections on the 2 fb^{-1} of the first phase of Run II.

The main goals of the B physics program at CDF for Run II are to provide a precision measurement of the angle β of the Unitarity Triangle as well as to exploit the B_s^0 and B_c^+ mesons and b baryons which will be a unique feature of hadron colliders. A precision measurement of B_s^0 flavor oscillations will be very important for testing the unitarity of the Cabibbo-Kobayashi-Maskawa (CKM) mixing matrix and the exploration of CP violation in B_s^0 decays could manifest physics beyond the Standard Model.

This paper is organized as follows. In section 2 we describe the Run II environment and the B physics triggers; in section 3 we present the prospects for the measurement of the angles α, β and γ of the Unitarity Triangle and of B_s^0 flavor oscillations. We also present plans for further studies of the B_s^0 meson as well as studies of the B_c^+ system and of rare B decays that are sensitive to new physics. Finally in section 4 we present our conclusions.

2 Run II Environment and B Physics Triggers

The rate of $b\bar{b}$ production at the Tevatron is considerably high, approximately 100 μb, and this, together with the fact that all b species are produced at the Tevatron, makes it a unique place for the study of b production and decay. Although the $b\bar{b}$ production cross section is only one part per thousand of the inelastic cross section, the CDF experiment has shown [1] that exclusive

B channels can be succesfully reconstructed in a harsh hadron environment.

The new crucial accelerator component for Run II is the main injector which has been commissioned successfully and which is expected to increase the rate of production of antiprotons by at least a factor of three above previous rates. Detector issues are driven by the luminosity, the number of bunches and the time between crossings of the protons and antiprotons. In Run I the crossing time was 3.5 μs for 6 bunches and the typical luminosity 0.16×10^{31} cm^{-2}sec^{-1}. The crossing times that are expected in Run II are 396 ns for 36 bunches and 132 ns for 121 bunches. The corresponding expected typical luminosities are 0.86×10^{32} cm^{-2}sec^{-1} and 1.62×10^{32} cm^{-2}sec^{-1} with peak luminosities of 2.0×10^{32} cm^{-2}sec^{-1}. The number of bunches and the luminosity together determine another key number, $< \mathrm{N}_{\mathrm{p\bar{p}}} >$, the average number of overlapping interactions in a given beam crossing. In the following studies we consider three operating scenarios at the Tevatron: Scenario A with 396 ns bunch spacing, luminosity of 0.7×10^{32} cm^{-2}sec^{-1} and $< \mathrm{N}_{\mathrm{p\bar{p}}} >=2$, scenario B with 132 ns bunch spacing, luminosity of 2.0×10^{32} cm^{-2}sec^{-1} and $< \mathrm{N}_{\mathrm{p\bar{p}}} >=2$ and scenario C with 396 ns bunch spacing, luminosity of 1.7×10^{32} cm^{-2}sec^{-1} and $< \mathrm{N}_{\mathrm{p\bar{p}}} >=5$.

At CDF the detector changes [2] are to the tracking system, to the calorimeters, to the muon systems, to the front-end electronics and trigger electronics and to the particle identification capabilities. There will be a new eight layer silicon system that extends from a radius of $r = 1.6$ cm from the beam line to $r = 28$ cm. The layer closest to the beam pipe is a radiation-hard, single-sided detector called Layer 00 which will employ recent LHC designs for sensors supporting high bias-voltages which enable good signal-to-noise performance even after extreme radiation doses. The remaining seven layers are radiation-hard, double-sided detectors. This system will allow track reconstruction in three dimensions and will have an impact parameter resolution better than 30 μm for tracks with transverse momentum 1 GeV/c. A new central drift chamber (COT) has been constructed as well, which will have a drift time that will be reduced by a factor of eight from Run I. dE/dx information for the tracks will be also provided by the COT. For Run II, the existing scintillator-based central calorimeters will continue to perform well. However, the gas calorimeters in the pseudorapidity region $|\eta| \geq 1.0$ are incompatible with the crossing rates for Run II, and are replaced with a new scintillating tile calorimeter. In the muon system some gaps will be closed in the azimuthal coverage for $|\eta| \leq 1.0$ and a new muon system is being built covering the region $1.0 \le |\eta| \le 1.5$. To accomodate a 132 ns bunch-crossing time and a 5.5 μs decision time for the first level trigger, all front-end electronics are fully pipelined with on-board buffering for 42 beam crossings. Finally a Time-of-flight (TOF) detector with expected resolution of 100 ps is being built which will allow a 2σ K/π separation for track momentum of less than 1.6 GeV/c. The CDF detector for Run II without the Layer 00 and the Time-of-flight detectors is often referred to as "Baseline CDF". Nevertheless, both these detectors have been already approved by the Fermilab Physics Advisory Committee as worthy additions to the baseline detector.

In Run II the trigger will continue to have three levels, but the throughput of each level will be increased by more than an order of magnitude from the Run I trigger to accomodate the shorter $\bar{p}p$ crossing interval and the order of magnitude increase in instantaneous luminosity in comparison with Run I. The maximum outputs of Level 1, Level 2 and Level 3 will be 50 kHz, 300 Hz and 75 Hz respectively. Fast tracking is now available at Level 1 with the XFT track processor which can find tracks of transverse momentum $p_T > 1.5$ GeV/c with a momentum resolution of $\delta p_T/p_T^2 < 0.015$ (GeV/c)$^{-1}$ and azimuthal resolution at the sixth superlayer of the COT $\delta\phi_6 < 0.0015$ rad. Information from the silicon detectors will be available at Level 2. The SVT trigger processor [2] associates clusters formed from axial strips in the silicon detectors with tracks of $p_T > 2$ GeV/c found by the XFT, providing a measurement of the impact parameter of the track in the plane transverse to the beam axis. This way it becomes possible to trigger on tracks originating from the decay of long-lived b hadrons and therefore coming from vertices different than the primary vertex of the $\bar{p}p$ collision. This will allow triggering on "all-hadronic" decays of b hadrons which are important for B_s^0 mixing studies and for the measurement of CP violation. The "all-hadronic" B decay trigger dominates the Level 1 bandwidth occupying up to 30 kHz, depending on the operating scenario, while it fits comfortably within the Level 2 bandwidth, requiring only up to 67 Hz.

3 B Physics Expectations for Run II

CDF will address many important questions in B physics in Run II. Many of the relevant measurements have already been investigated using the Run I data. In the following subsections we summarize the studies performed and the expectations for these future topics.

3.1 Measurement of $\sin(2\beta)$

In the B system the measurements of CP violation that are related (without large theoretical uncertainties) to angles of the Unitarity Triangle are from asymmetries in the decays of neutral B mesons to CP eigenstates. For the measurement of the angle β the most popular mode is $B^0/\bar{B}^0 \to J/\psi K_s^0$. CP violation is expected to manifest itself as an asymmetry in the particle decay rate versus antiparticle decay rate to $J/\psi K_s^0$:

$$A_{CP} = \frac{N(\bar{B}^0 \to J/\psi K_s^0) - N(B^0 \to J/\psi K_s^0)}{N(\bar{B}^0 \to J/\psi K_s^0) + N(B^0 \to J/\psi K_s^0)}$$

where $N(\bar{B}^0 \to J/\psi K_s^0)$ is the number of mesons decaying to $J/\psi K_s^0$ that were produced as $\bar{B}^0$ and $N(B^0 \to J/\psi K_s^0)$ is the number of mesons decaying to $J/\psi K_s^0$ that were produced as B^0. In the Standard Model the CP asymmetry in this decay mode is proportional to $\sin(2\beta)$: $A_{CP}(t) = \sin(2\beta)\sin(\Delta m_d t)$, where β is the angle of the Unitarity Triangle and Δm_d is the mass difference between the heavy and light B^0 eigenstates. Even though the time integrated asymmetry can be used to extract $\sin(2\beta)$, measuring the asymmetry as a function of proper decay time is more advantageous. For the measurement of $A_{CP}(t)$ we need to reconstruct the decay mode $B^0/\bar{B}^0 \to J/\psi K_s^0$ with good signal-to-background ratio, measure the proper decay time t and determine whether the meson that decayed was produced as a B^0 or as a $\bar{B}^0$. This last component is known as "b flavor tagging". The performance of the b flavor tags can be quantified by their efficiency ϵ and dilution D. The efficiency is the fraction of B candidates to which the flavor tag can be applied. The dilution is related to the probability P that the tag is correct: $D = 2P - 1$, that is, a perfect tag has $D = 1$ and a random tag has $D = 0$. The experimentally measured asymmetry or observed asymmetry is reduced by the dilution of the tag: $A_{CP}^{obs} = DA_{CP}$. The uncertainty in the asymmetry is inversely proportional to the square root of $\epsilon D^2 N$ where N is the number of events before the flavor tagging. The product ϵD^2 is usually called "flavor tag effectiveness". As discussed in [1], using the entire Run I data and three tagging algorithms we find $\sin(2\beta) = 0.79^{+0.41}_{-0.44}$ (stat.+syst.).

The measurement is based on 395$\pm$31 $B^0/\bar{B}^0 \rightarrow J/\psi K^0_s$; $J/\psi \rightarrow \mu^+\mu^-$, $K^0_s \rightarrow \pi^+\pi^-$ events from which 202$\pm$18 were reconstructed in the silicon vertex detector.

In Run II the signal size should increase to 10,000 $B^0/\bar{B}^0 \rightarrow J/\psi K^0_s$ decays where $J/\psi \rightarrow \mu^+\mu^-$ and $K^0_s \rightarrow \pi^+\pi^-$. A further increase in this number could come from a 10% increase in the b production cross section at $\sqrt{s} = 2.0$ TeV and from a 36% increase from relaxing the Level 1 muon stub finding requirements to obtain a better trigger efficiency near trigger threshold. CDF also plans to trigger on $J/\psi \rightarrow e^+e^-$ which would increase the number of $J/\psi K^0_s$ events by approximately 50% [2]. The b flavor tags will be calibrated with approximately 40,000 $B^\pm \rightarrow J/\psi K^\pm$ decays and 20,000 $B^0/\bar{B}^0 \rightarrow J/\psi K^{*0}/\bar{K}^{*0}$ decays.

The expected combined flavor tag effectiveness for Run II based on "same side tagging", "soft lepton tagging" and "jet charge tagging" [1] is $\epsilon D^2 =$ 6.7%. Assuming a yield of 10,000 $B^0/\bar{B}^0 \rightarrow J/\psi K^0_s$ events, the resulting estimate of the error on $\sin(2\beta)$ is $\delta(\sin(2\beta)) = 0.084$. This uncertainty includes the systematic uncertainties in the dilutions due to the statistics of the calibration samples. The TOF detector will make it possible to use a new flavor tag based on kaons, since the decays of b hadrons containing $\bar{b}(b)$ quarks usually produce K$^+$(K$^-$). With this additional flavor tag, the total flavor tag effectiveness could increase to $\epsilon D^2 =$9.1% [3], resulting in an error on $\sin(2\beta)$ of $\delta(\sin(2\beta)) = 0.07$.

3.2 Measurement of $\sin(2\alpha)$

CDF has considered extracting $\sin(2\alpha)$ from the measurement of the asymmetry in the decay $B^0 \rightarrow \pi^+\pi^-$. The greatest challenge in this measurement is the trigger requirement.

At Level 1 two oppositely charged tracks found by the XFT processor are used and at Level 2 we use the SVT which measures the impact parameter of the tracks sufficiently precisely to distiguish tracks coming from heavy flavor decays from tracks coming from QCD jets, which have non-zero impact parameter only due to measurement resolution. The trigger rates have been studied using minimum bias data for Level 1 and data sets collected with specialized test triggers taken during Run I for Level 2. The maximum expected trigger rates are 30 KHz at Level 1 and 39 Hz at Level 2. The SVT plays a very important role by reducing the trigger rate by approximately three orders of magnitude.

The $B^0 \to \pi^+\pi^-$ signal yield is obtained from Monte Carlo simulation [3]. Assuming $BR(B^0 \to \pi^+\pi^-) = (4.7^{+1.8}_{-1.5} \pm 0.6) \times 10^{-6}$ [4], CDF expects 7,144, 5,546 and 3,948 events in 2 fb^{-1} of data for the Tevatron operating scenarios A, B and C respectively. Combinatorial backgrounds have been studied using specialized test trigger data from Run I. To measure the CP asymmetry in $B^0 \to \pi^+\pi^-$ events one needs to study as well the *physics* backgrounds from $B^0 \to K\pi$, $B^0_s \to K\pi$ and $B^0_s \to KK$ decays. These backgrounds can be extracted from the untagged sample by making use of the invariant $\pi\pi$ mass distribution as well as the dE/dx information provided by the COT. We expect a $K - \pi$ separation of 1.3 σ for track momentum $p_T > 2$ GeV/c. An initial simulation [2] indicates that the invariant mass resolution at $p_T(B)$ of 6 GeV/c will be about 20 MeV/c^2. The $B^0_s \to K^+K^-$ peak lies directly under the $B^0 \to \pi^+\pi^-$ signal and it requires particle identification through dE/dx and TOF as well as a time dependent analysis. For our estimate of the uncertainty on the CP aymmetry, we use a signal-to-background ratio of 1:4. Assuming the same flavor tagging effectiveness ϵD^2 =9.1% as in the $J/\psi K^0_s$ case, a yield of 4,700 $B^0 \to \pi^+\pi^-$ events and considering a time integrated asymmetry only, CDF expects to measure the CP aymmetry from $B^0 \to \pi^+\pi^-$ with an uncertainty of 0.13.

The final issue related to the extraction of the angle α from the measured time dependence of the CP asymmetry is the extraction of possible penguin contributions, in addition to the tree level diagrams, requiring theoretical input. As discussed in reference [5], the decay $B^0 \to \rho\pi^0 \to \pi^+\pi^-\pi^0$ provides enough observables to determine α from an analysis of the time-dependent three-pion Dalitz plot. This method provides a promising alternative way to determine $\sin(2\alpha)$, however, the reconstruction of low momentum π^0 mesons from their decays into two photons will be very challenging for CDF in Run II.

3.3 Prospects for $B^0_s - \bar{B}^0_s$ mixing

In the Standard Model, $B^0_s\bar{B}^0_s$ oscillations occur dominantly through top quark contributions to the electroweak box diagram. The size of the mixing is expressed in terms of the parameter x_s which is related to the mass difference between the two mass eigenstates and the average lifetime of the states by $x_s = \Delta m_s \tau(B^0_s)$. The value of x_s depends on the top quark mass, the B_s

decay constant, the QCD bag parameters and corrections due to the breaking of SU(3) flavor symmetry.

The B_s^0 decay modes used in these studies are $B_s^0 \to D_s^- \pi^+$ and $B_s^0 \to D_s^- \pi^+ \pi^- \pi^+$ where the D_s^- is reconstructed as $\phi\pi^-$ or $K^{*0}K^-$. For the determination of the signal yield we assumed $BR(D_s^- \pi^+) = (0.30 \pm 0.04)\%$ and $BR(D_s^- \pi^+ \pi^- \pi^+) = (0.80 \pm 0.25)\%$ [3].

The data collection of B_s^0 decay modes is based on the two-track trigger used for the collection of $B^0 \to \pi^+\pi^-$ events. We expect 10,600 events in the $D_s^- \pi^+$ decay mode and 12,800 events in the $D_s^- \pi^+ \pi^- \pi^+$ decay mode for scenario A; 8,400 events in the $D_s^- \pi^+$ decay mode and 10,400 events in the $D_s^- \pi^+ \pi^- \pi^+$ decay mode for scenario B; and 7,200 events in the $D_s^- \pi^+$ decay mode and 8,100 events in the $D_s^- \pi^+ \pi^- \pi^+$ decay mode for scenario C. When we evaluate the x_s reach, we vary the total number of events in these two decay modes from 5,000 to 30,000; these numbers are for the two modes combined. For the extraction of the signals from combinatorial background we estimate a signal-to-background ratio in the range 1:2 to 2:1 [3].

For the evaluation of our sensitivity to $B_s^0 \bar{B}_s^0$ oscillations the beyond-the-baseline upgrades, Layer 00 and TOF, play an important role. The addition of Layer 00 will provide more precise decay lenght measurements which will improve the proper time resolution from $\sigma_t = 60$ fs to $\sigma_t = 45$ fs. The TOF system is expected to improve the ϵD^2 flavor tag effectiveness from 5.7% to 11.3%. Figure 1 shows the significance of observing $B_s^0 \bar{B}_s^0$ mixing as a function of x_s for different upgrade scenarios and for signal-to-background ratios of 2:1 and 1:2. The curves shown in the figure assume 20,000 reconstructed B_s^0 decays. Table 1 shows the maximum value of x_s for which an observation of $B_s^0 \bar{B}_s^0$ mixing would be made with a significance of at least 5σ for various values of $N(B_s^0)$ and for signal-to-background ratios of 2:1 and 1:2. We also show in Table 1 how low the signal-to-background ratio can be, before a 5σ observation of $B_s^0 \bar{B}_s^0$ oscillations can no longer be made, for x_s =30 and x_s =40. Each time we compare the prospects with the baseline detector versus the addition of the beyond-the-baseline upgrades TOF plus Layer 00.

A precision measurement of B_s^0 flavor oscillations, combined with existing measurements of B^0 oscillations, will be very important for testing the unitarity of the CKM mixing matrix. The combined world average lower limit in B_s^0 flavor oscillations [6] is currently $x_s > 22$ ($\Delta m_s > 14.3$ ps) at 95% C.L. The currently favoured value of the Standard Model for x_s [7] is in the range

$18 < x_s < 27$ with a 95% C.L. limit of $x_s < 31$. Therefore, the expected CDF reach in Run II covers well the currently favoured values of x_s within the Standard Model.

3.4 CP asymmetry in $B_s^0 \to J/\psi\phi$

While the CP asymmetry in $B^0/\bar{B}^0 \to J/\psi K_s^0$ measures the weak phase of the CKM matrix element V_{td}, the CP asymmetry in $B_s^0/\bar{B}_s^0 \to J/\psi\phi$ measures the weak phase of V_{ts} which is expected to be very small within the Standard Model. Observing an asymmetry in $B_s^0/\bar{B}_s^0 \to J/\psi\phi$ would signal the existence of an anomalous CP violating phase [5].

On the basis of our Run I experience, we expect that the yield of $B_s^0 \to J/\psi\phi$ in Run II will be about 60% of the $B_s^0 \to J/\psi K_s$ yield. The flavor tagging efficiencies for $B_s^0 \to J/\psi\phi$ are expected to be 4.9% without the TOF detector and 9.7% with the TOF detector. An angular analysis may be necessary to separate the different possible CP eigenstates contributing to this final state. If we neglect any loss of sensitivity due to this procedure and with the assumptions stated above, the uncertainty in the CP asymmetry for $B_s^0 \to J/\psi\phi$ as a function of x_s is shown in Fig. 2. We see that the sensitivity is improved significantly with the Layer 00 and TOF detectors.

3.5 Measurement of sinγ

One of the best tools to extract the angle γ are measurements of the time-dependent asymmetries in B_s^0 decays. CDF has considered measuring γ using the decays $B_s^0 \to D_s^- K^+$ and $B^\pm \to DK^\pm$.

Data for the first decay mode will be collected with the same two-track trigger as for $B^0 \to \pi^+\pi^-$ and $B_s^0 \to D_s^-\pi^+$. In 2 fb^{-1} of data we expect to have about 700 $B_s^0 \to D_s^- K^+$ signal events before flavor tagging. In order to estimate the signal-to-background ratio we considered physics backgrounds and combinatorial background. The main physics background is from $B_s^0 \to D_s^{*-}\pi^+$ decays which is ten times larger than our signal. Preliminary studies indicate that a combination of dE/dx and TOF information together with the $\sim$ 20 MeV/c^2 mass resolution for the respective B signal should achieve a signal-to-background ratio of 1:1. For the combinatorial background we expect to achieve a signal-to-background ratio of 1:5. Therefore in our studies we vary the signal-to-background ratio for the sum of the backgrounds from 1:1 to 1:6.

To estimate our reach for sinγ, we performed Monte Carlo studies generating pseudo-experiments which included signal, backgrounds, resolution smearing as well as mistagging. Each pseudo-experiment is subjected to a fitter extracting $\sin(\gamma + \delta)$ and $\sin(\gamma - \delta)$ as fit parameters where δ is the strong phase. The distribution of errors from 1000 pseudo-experiments and for x_d =0.723, strong phase δ =0, x_s =25, proper time resolution σ_t = 45 fs and flavor tag effectiveness ϵD^2 =11.3% yields a most probable uncertainty on $\sin(\gamma \pm \delta)$ of 0.43(0.79) for signal-to-background ratios equal to 1:1(1:6). We varied x_s in the range 20 to 50, the proper time resolution in the range 30 fs to 60 fs and ϵD^2 in the range 5.7% to 11.3%; we see that the uncertainties behave according to expection.

Another way to extract the CKM angle γ had been originally suggested by Gronau, London and Wyler [8]. It is based on measuring $B^{\pm}$ decay rates involving $D^0/\bar{D}^0$ mesons and requires the interference between two amplitudes that are significantly different in magnitude causing the resulting asymmetries to be small. A refinement of this method has recently been suggested by Atwood, Dunietz and Soni [9] using decays to final states that are common to both D^0 and $\bar{D}^0$ and that are not CP eigenstates. In particular, large CP asymmetries can result from the interference of the decays $B^- \to K^- D^0$ and $B^- \to K^- \bar{D}^0$ with $D^0 \to f$ being a doubly Cabibbo suppressed decay while $\bar{D}^0 \to f$ is Cabibbo allowed. The measurement of interference effects in these modes allows the extraction of γ without the knowledge of $BR(B^- \to K^- \bar{D}^0)$.

In a very preliminary study, CDF has investigated the two D^0 final states $K^-\pi^+$ and $K^-\pi^+\pi^-\pi^+$. The $B^- \to K^- D$ data samples would be collected using the two-track hadronic trigger used for $B^0 \to \pi^+\pi^-$ or hadronic B_s^0 decays. We would expect to record about 100 to 150 events for $B^- \to K^- D^0$ with $D^0 \to K^-\pi^+$ and about the same number for $D^0 \to K^-\pi^+\pi^-\pi^+$ in 2 fb^{-1} for the three trigger scenarios of the Tevatron. Our studies indicate that a resolution on γ of $\sim 20^\circ$ could be possible with an uncertainty of 15% on the necessary branching ratios and signal-to-background ratios as low as 1:20. Our signal-to-background ratio studies refer to *physics* backgrounds only. A detailed study of the contribution of combinatorial background has not yet been performed.

3.6 B_c^+ mesons and rare B decays

We expect three major contributions to the B_c^+ decay width: $\bar{b} \to \bar{c}W^+$ with the $c\bar{c}$ as a spectator, leading to final states like $J/\psi\,\pi$ or $J/\psi\,\ell\nu$; $c \to sW^+$, with the $b\bar{b}$ as spectator, leading to final states like $B_s^0\,\pi^+$ or $B_s^0\,\ell^+\nu$; and $c\bar{b} \to W^+$ annihilation, leading to final states like $D\,K$, $\tau\,\nu_\tau$ or multiple pions. CDF searched for the decay channels $B_c^+ \to J/\psi\,\mu^+\,\nu$ and $B_c^+ \to J/\psi\,e^+\,\nu$ followed by $J/\psi \to \mu^+\mu^-$. We observed $20.4^{+6.2}_{-5.5}$ events in these decay channels and measured the B_c^+ mass to be $6.40 \pm 0.39(stat.) \pm 0.13(syst.)$ GeV/c^2 and the B_c^+ lifetime to be $0.46^{+0.18}_{-0.16}(stat.) \pm 0.03(syst.)$ ps [10]. The increase of statistics expected in Run II of the Tevatron Collider (increase in yield by at least a factor of 50 in the J/ψ decay modes for the first 2 fb^{-1}), combined with refinement in technique and investigation of additional decay channels for the B_c^+ meson should allow us to measure its mass, lifetime and production cross section with much better accuracy than we did with the currently available data. It should also allow us to measure ratios of branching ratios of the B_c^+ for various decay channels. Let us note here that the mass uncertainty from the B_c^+ hadronic channels involving a J/ψ is about 8 MeV/c^2, to be compared with the 411 MeV/c^2 uncertainty we achieved in Run I with the semileptonic decay modes.

Rare B decays provide a stringent test of the Standard Model for possible new physics effects, such as an anomalous magnetic moment of the W and the presence of a charged Higgs. Experimentally, these rare decays are accessible at CDF via the dimuon trigger, which is one of the most important B physics triggers. CDF has performed a search for the decay modes $B^\pm \to \mu^+\mu^-K^\pm$, $B^0 \to \mu^+\mu^-K^{*0}$ and $B^0_{d,s} \to \mu^+\mu^-$ [11] using Run I data. The standard Model predictions [12] for the branching ratio for these decay modes, together with the expected sensitivity for the first phase of Run II are listed in Table 2. The projections for $B^\pm \to \mu^+\mu^-K^\pm$ and $B^0 \to \mu^+\mu^-K^{*0}$ assume a conservative signal-to-background ratio of 1:10. Assuming Standard Model branching ratios for $B^\pm \to \mu^+\mu^-K^\pm$ and $B^0 \to \mu^+\mu^-K^{*0}$, we will have visible signals for these decays. In particular, we expect between 100 and 300 $B^\pm \to \mu^+\mu^-K^\pm$ events and between 400 and 1100 $B^0 \to \mu^+\mu^-K^{*0}$ events. This will enable us to study both the invariant mass distribution of the dimuon pair and the forward-backward charge asymmetry in the decay. Both of these distributions are sensitive to physics beyond the Standard Model [13].

4 Conclusions

CDF has established a rich and competative B physics program and plans to fully exploit in Run II the copious production of b hadrons in all of the species produced at the Tevatron. With the experience gained so far in the analyses of Run I data and the planned capabilities of the Run II detector we are able to confidently project our expectations for Run II which include: measurement of $\sin(2\beta)$ with an uncertainty of 0.07; measurement of the CP aymmetry from the decay $B^0 \to \pi^+\pi^-$ with an uncertainty of 0.13; a five standard deviation sensitivity for a $B_s^0 - \bar{B}_s^0$ mixing measurement up to $x_s = 63$; sensitivity to CP asymmetry in the decay $B_s^0 \to J/\psi\phi$ of 10% uncertainty for $x_s = 25$; studies of the B_c^+ meson, of b baryons and of rare B decays.

With these and other measurements that we will pursue in Run II, we expect to impose severe constraints on the Standard Model of weak quark mixing and CP violation and be sensitive to new physics.

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$N(B_s^0)$	S/B=2:1 Baseline	BTB	S/B=1:2 Baseline	BTB	$x_s = 30$ Baseline	BTB	$x_s = 40$ Baseline	BTB
5,000	30	49	21	39	2.20	0.24	—	0.53
10,000	37	56	30	49	0.52	0.11	—	0.21
20,000	42	63	37	56	0.21	0.05	0.99	0.10
30,000	45	67	40	60	0.13	0.03	0.50	0.06

Table 1: *Left:* Maximum values of x_s for which an observation of B_s^0 mixing could be made with at least 5σ significance. Values for signal-to-background ratios of 2:1 and 1:2 are shown. *Right:* Minimum values of the signal-to-background ratio for which an observation of B_s^0 mixing could be made with at least 5σ significance, for $x_s = 30$ and $x_s = 40$. The dashes indicate scenarios for which a 5σ observation could not be made even in the absence of any background. BTB refers to the addition of the beyond-the-baseline detectors TOF plus Layer 00.

B Decay Mode	Standard Model	CDF Run II
$\mu^+\mu^- K^\pm$	(2-5)$\times$ 10^{-7}	2 $\times$ 10^{-7}
$\mu^+\mu^- K^{*0}$	(2-5)$\times$ 10^{-6}	4 $\times$ 10^{-7}
$B_d \to \mu^+\mu^-$	(0.6-1.9)$\times$ 10^{-10}	1 $\times$ 10^{-8}
$B_s \to \mu^+\mu^-$	(1.5-4.5)$\times$ 10^{-9}	4 $\times$ 10^{-8}

Table 2: Rare B decay modes, Standard Model predictions for their branching ratios and the expected sensitivity (90% C.L.) for 2 fb^{-1} of data in Run II.

FIGURE CAPTIONS

1) Effects of background levels on x_s reach in Run II for the CDF baseline configuration and with the beyond-the-baseline upgrades assuming $N(B_s^0)$ = 20,000 and signal-to-background ratios of 2:1 (left) and 1:2 (right).

2) The uncertainty on the CP asymmetry for $B_s^0 \to J/\psi\phi$ as a function of the B_s^0 mixing parameter x_s. The top curve is for the baseline CDF detector, while the bottom curve includes improvements from Time-of-flight and the Layer 00.

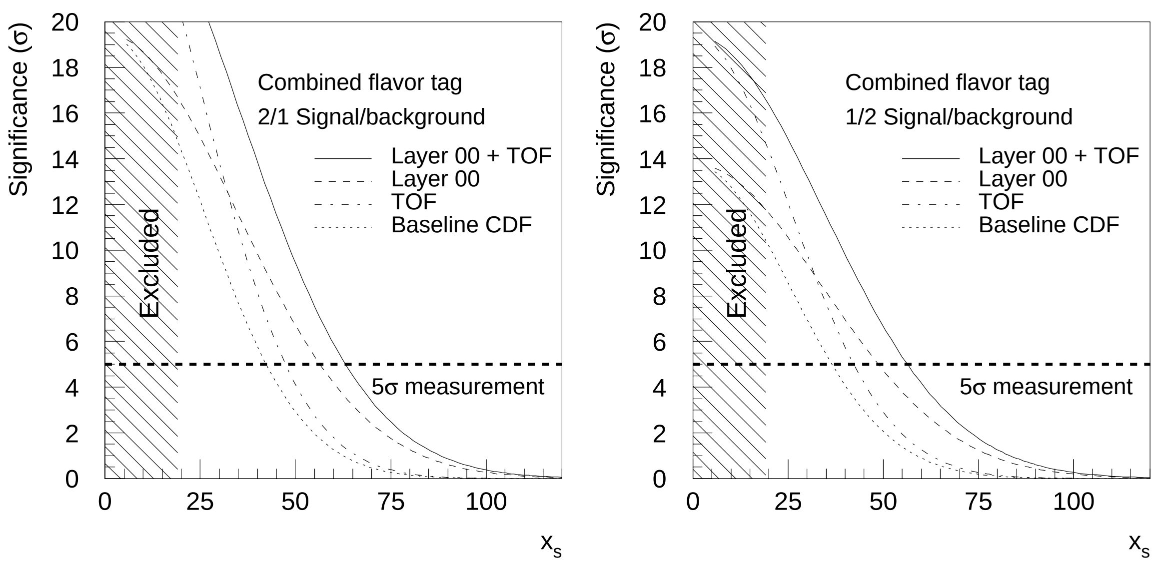

Figure 1: Effects of background levels on x_s reach in Run II for the CDF baseline configuration and with the beyond-the-baseline upgrades assuming $N(B_s^0) = 20{,}000$ and signal-to-background ratios of 2:1 (left) and 1:2 (right).

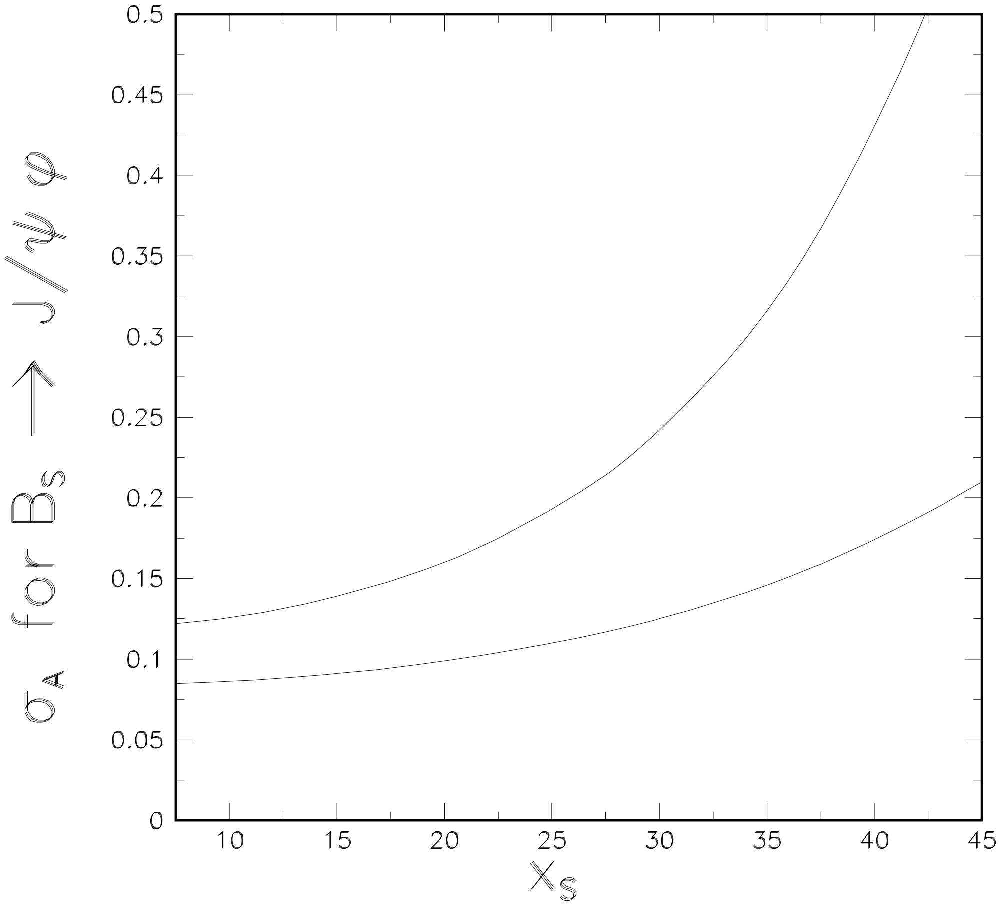

Figure 2: The uncertainty on the CP asymmetry for $B_s^0 \to J/\psi\phi$ as a function of the B_s^0 mixing parameter x_s. The top curve is for the baseline CDF detector, while the bottom curve includes improvements from Time-of-flight and the Layer 00.