

CDF Run I B Physics Results

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Abstract

The CDF Run I B physics program has been very successful, making numerous measurements over a wide variety of B physics topics. Measurements have included masses and lifetimes; discovery of the B_c ; $B_s \rightarrow J/\psi\phi$ polarization; $B^0 \leftrightarrow \bar{B}^0$ mixing; $\sin(2\beta)$; and rare decay limits. Recent results include a search for $\Lambda_b \rightarrow \Lambda\gamma$ and a study of $B^0 \rightarrow J/\psi K^{(*)0}\pi^+\pi^-$ decays. The tools and experience developed during Run I are quite valuable as CDF enters Run II.

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1 Introduction

Over the past decade, the Collider Detector at Fermilab (CDF) collaboration has produced many precision B physics measurements through its extremely successful B physics program. Nearly 50 B physics papers have been published and several more are in process. The primary advantages of hadron machines for B physics are twofold: a large b quark production cross section combined with the ability to produce all forms of b mesons and baryons. The primary disadvantage is that the cross section for generic QCD background is even larger than the b production cross section. Over the course of Run I CDF capitalized upon the advantages and overcame the disadvantages to produce many precision measurements across a wide variety of B physics topics. An overview of these results is presented in section 2, while section 3 focuses on a few recent results. Conclusions are given in section 4.

2 Overview of Results

As mentioned in the introduction, the b quark production cross section is quite large in hadronic collisions. CDF has measured the integrated production cross section for B mesons with transverse momentum $p_T(B) > 6.0$ GeV/ c and rapidity $|y| < 1.0$ to be $2.54 \pm 0.22 \pm 0.53$ μb [1]. This is orders of magnitude larger than the production cross section at $\Upsilon(4S)$ or Z^0 . The differential cross section is also consistently higher than QCD theory across the full $p_T(b)$ spectrum, as shown in figure 1.

CDF has also made measurements of the masses and lifetimes of B^\pm , B^0 , B_s , B_c , and Λ_b [2, 3]. In the case of B^\pm and B^0 , the CDF results contribute significantly to the world average while the B_s and B_c results and the Λ_b mass measurement represent the world's best (or only) measurements of these quantities.

One of the strengths of CDF is the ability to study B_s mesons. In addition to mass and lifetime measurements, Run I B_s studies have set a B_s mixing limit of $\Delta m_s > 5.8$ ps $^{-1}$ [4] and measured polarization in $B_s \rightarrow J/\psi\phi$ [7]. These measurements set the stage for CDF Run II B_s studies which will include B_s mixing, the CP -even $vs.$ -odd lifetime difference, and CP violation searches.

A highlight of the CDF Run I B physics program was the measurement of $\sin(2\beta) = 0.79_{-0.44}^{+0.41}$ [5]. This measurement used approximately 400 $B^0 \rightarrow$

$J/\psi K_S^0$ decays and three different B flavor tagging methods. One of the flavor tagging algorithms, same-side tagging, was discovered at CDF [6] and will be a crucial tool for future measurements of CP violation and B_s mixing.

Table 1 shows the CDF Run I rare decay limits [8]. $\text{BR}(B^0 \rightarrow \mu^+ \mu^- K^{*0}) < 4.0 \times 10^{-6}$ is especially promising since it is near the Standard Model prediction of $(1.0 - 1.5) \times 10^{-6}$.

3 Recent Results

3.1 Search for $\Lambda_b \rightarrow \Lambda \gamma$

A recent study performed the first search for baryonic electroweak penguin decays in $\Lambda_b \rightarrow \Lambda \gamma$. Like other electroweak penguin decays, this mode is sensitive to new physics contributions, both in the decay rate and in the polarization of the Λ in its rest frame with respect to the direction of the Λ momentum in the Λ_b rest frame [9].

The search looked for $\Lambda \rightarrow p\pi$ and $\gamma \rightarrow e^+e^-$ using γ conversions in the inner detector. The cuts optimized $\epsilon_{sig}/\sqrt{\epsilon_{bkg}}$ where ϵ_{sig} and ϵ_{bkg} are the signal and background efficiencies, respectively. The signal efficiency was determined using a Monte Carlo simulation while the backgrounds were modeled using the events in the sidebands of the Λ_b mass plot. The mode $B^+ \rightarrow J/\psi(\rightarrow e^+e^-)K^+$ was used for efficiency normalization for determining the branching ratio limit. The results are shown in figure 2 with two events in the cross hatched signal region with an expected background of 3.4 ± 0.6 events (top) compared with 24.0 ± 5.3 events in the reference mode signal region (bottom). After considering the various efficiencies for the signal and reference modes and their uncertainties, these results correspond to a 90% confidence level branching ratio limit of

$$\text{BR}(\Lambda_b \rightarrow \Lambda \gamma) < 6.5 \times 10^{-4}. \quad (1)$$

In comparison, Standard Model predictions are in the range $0.2 - 5 \times 10^{-5}$ [9].

3.2 Study of $B^0 \rightarrow J/\psi K_S^0 \pi^+ \pi^-$

Another recent study has searched for $B^0 \rightarrow J/\psi K_S^0 \pi^+ \pi^-$ decays with a particular interest in the $B^0 \rightarrow J/\psi K_S^0 \rho^0$ contribution. Like $J/\psi K_S^0$, both

B^0 and \bar{B}^0 can decay to this final state making this mode sensitive to CP violation due to mixing. Unlike $J/\psi K_S^0$, however, $J/\psi K_S^0 \rho^0$ is not a CP eigenstate, thus it allows interference terms between the CP -even and CP -odd contributions. These cross terms are proportional to $\cos(2\beta)$, a quantity whose measurement (or even sign) is useful for resolving the four-fold discrete ambiguities on β from a $\sin(2\beta)$ measurement.

The search cuts were optimized using $B^0 \rightarrow J/\psi K_S^0$ as a reference signal. The resulting mass peak is shown at the top of figure 3 with 15.7 ± 4.3 events. The bottom plot in figure 3 shows the $B^0 \rightarrow J/\psi K_S^0 \rho^0$ candidate events remaining after $B^0 \rightarrow J/\psi K^{*+} \pi^-$ candidates have been removed. With such limited statistics, it is difficult to uniquely identify the $\rho^0 \rightarrow \pi^+ \pi^-$ contribution, but the events within the B^0 mass region fall within the ρ^0 spread and do not extend as wide as would be expected from non-resonant $\pi^+ \pi^-$ or other possible decay contributions such as $B^0 \rightarrow J/\psi K_0^*(1430)^+ \pi^-$. If these events are due to $B^0 \rightarrow J/\psi K_S^0 \rho^0$ and there is no interference with the $B^0 \rightarrow J/\psi K^{*+} \pi^-$ contribution, this corresponds to a branching ratio of:

$$\text{BR}(B^0 \rightarrow J/\psi K_S^0 \rho^0) = (5.5 \pm 2.5_{-1.1}^{+1.0}) \times 10^{-4}. \quad (2)$$

The $K_S^0 \pi^+ \pi^-$ mass plot indicates that some, but not all, of the signal events come from $B^0 \rightarrow J/\psi K_1(1270)$.

3.3 Other

The analyses presented here are just a selection of several recent Run I analyses. Other ongoing analyses include B_s mixing limits and measurements of $\text{BR}(B^+ \rightarrow J/\psi K^+ \pi^+ \pi^-) = (1.2 \pm 0.3 \pm 0.2) \times 10^{-3}$; $\text{BR}(B^+ \rightarrow \chi_c K^+) = (10.4 \pm 3.6 \pm 1.6) \times 10^{-4}$; $\text{BR}(B^0 \rightarrow J/\psi K^{*0} \pi^+ \pi^-) = (5.3 \pm 1.1_{-0.9}^{+0.8}) \times 10^{-4}$; $\text{BR}(B_s \rightarrow J/\psi \bar{K}^{*0}) < 8.5 \times 10^{-5}$; and a search for $B_s \rightarrow J/\psi K^{(*)0} \bar{K}^{(*)0}$.

4 Conclusions

Much has been accomplished in the CDF Run I B physics program. We have capitalized upon the advantages of the hadronic environment while overcoming the primary disadvantage of large QCD backgrounds. In addition to demonstrating precision B physics measurements at a hadronic accelerator, we have developed tools and experience which are crucial as we enter Run II. We expect many new results in Run II while receiving stiff competition

from the e^+e^- B factories. All of this has been accomplished at CDF using what is in essence a general purpose high energy particle detector. When CDF Run II ends, we look forward to a strong continuation of B physics in the hadronic environment at the dedicated B physics experiments of B TeV and LHCb. It is an exciting time for B physics and hadronic machines are a great place to be.

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Mode	BR Limit (90% CL)
$B^0 \rightarrow K^{*0} \gamma$	1.1×10^{-4}
$B_s \rightarrow \phi \gamma$	1.2×10^{-4}
$B_s \rightarrow \mu^+ \mu^- \phi$	4.2×10^{-5}
$B^+ \rightarrow \mu^+ \mu^- K^+$	5.2×10^{-6}
$B^0 \rightarrow \mu^+ \mu^- K^{*0}$	4.0×10^{-6}
$B^0 \rightarrow \mu^+ \mu^-$	8.6×10^{-7}
$B_s \rightarrow \mu^+ \mu^-$	2.6×10^{-6}

Table 1: CDF rare B decay limits.

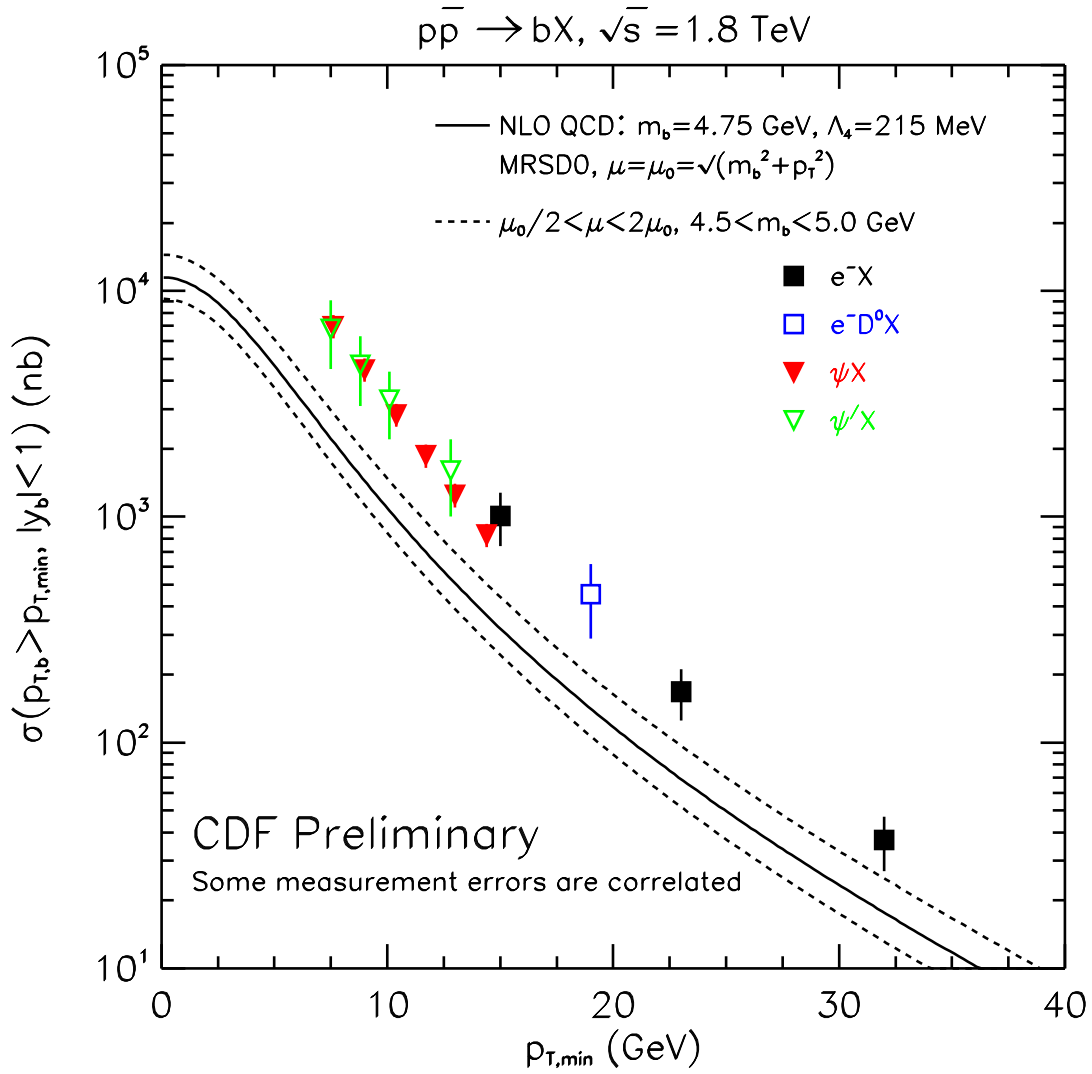


Figure 1: b differential production cross section at $\sqrt{s} = 1.8 \text{ TeV}$.

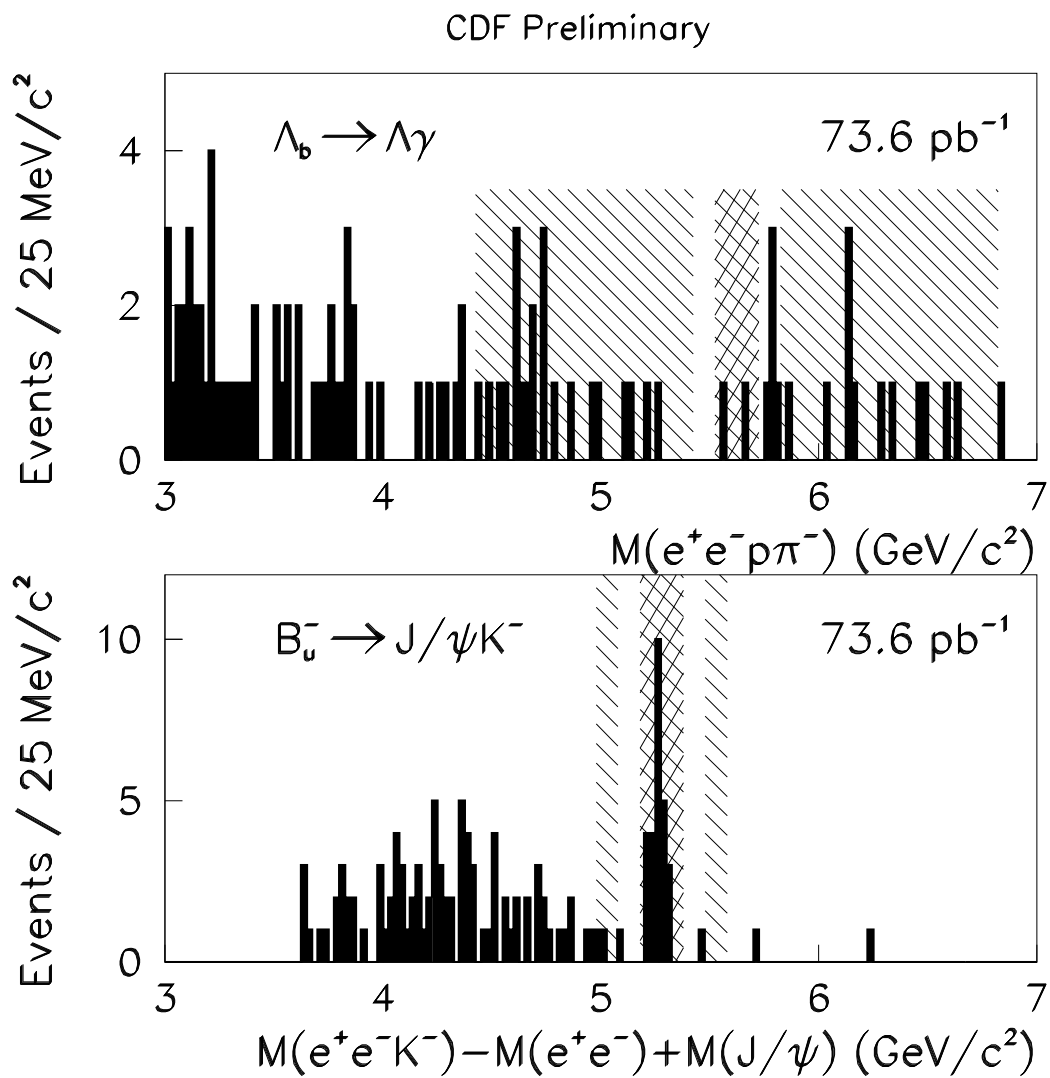


Figure 2: $\Lambda_b \rightarrow \Lambda \gamma$ candidates (top) compared to the $B^- \rightarrow J/\psi(\rightarrow e^+e^-)K^-$ reference signal (bottom).

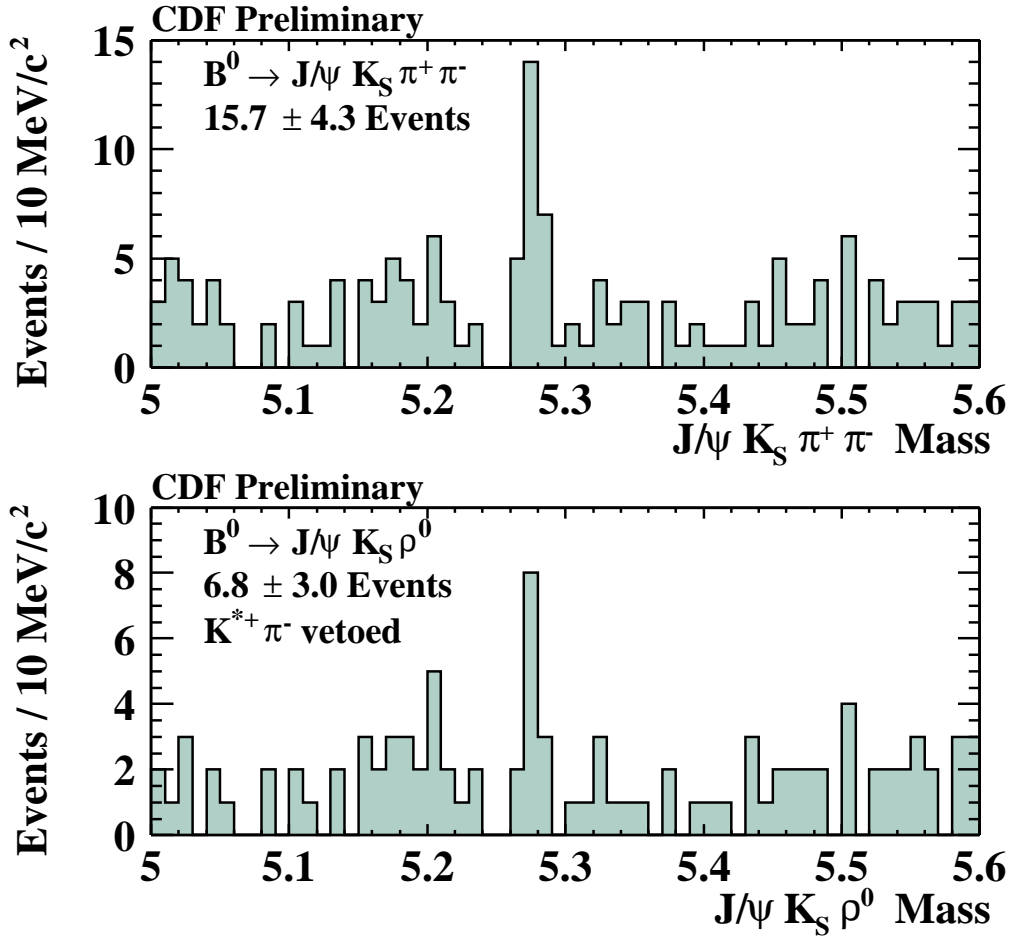


Figure 3: $B^0 \rightarrow J/\psi K_S^0 \pi^+ \pi^-$ candidate mass peak (top) with 15.7 ± 4.3 events. The bottom plot shows the $B^0 \rightarrow J/\psi K_S^0 \rho^0$ events remaining after $B^0 \rightarrow J/\psi K^{*+} \pi^-$ candidates have been removed.