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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; $B_s \to J/\psi\phi$ polarization; $B^0 \leftrightarrow \bar{B}^0$ mixing; $\sin(2\beta)$; and rare decay limits. Recent results include a search for $\Lambda_b \to \Lambda\gamma$ and a study of $B^0 \to J/\psi K^{(*)0}\pi^+\pi^-$ 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 $B_s \to J/\psi\phi$ [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 $\sin(2\beta) = 0.79^{+0.41}_{-0.44}$ [5]. This measurement used approximately 400 $B^0 \to$

$J/\psi K_S^0$ 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]. BR($B^0 \to \mu^+\mu^- K^{*0}$) $< 4.0 \times 10^{-6}$ 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 $\Lambda_b \to \Lambda\gamma$

A recent study performed the first search for baryonic electroweak penguin decays in $\Lambda_b \to \Lambda\gamma$. 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 $\Lambda \to \mathrm{p}\pi$ and $\gamma \to e^+e^-$ 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 $B^+ \to J/\psi(\to e^+e^-)K^+$ 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

$$\mathrm{BR}(\Lambda_b \to \Lambda\gamma) < 6.5 \times 10^{-4}. \tag{1}$$

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

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

Another recent study has searched for $B^0 \to J/\psi K_S^0 \pi^+\pi^-$ decays with a particular interest in the $B^0 \to J/\psi K_S^0 \rho^0$ 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 discreet ambiguities on β from a $\sin(2\beta)$ measurement.

The search cuts were optimized using $B^0 \to J/\psi K_S^0$ 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 $B^0 \to J/\psi K_S^0 \rho^0$ candidate events remaining after $B^0 \to J/\psi K^{*+}\pi^-$ candidates have been removed. With such limited statistics, it is difficult to uniquely identify the $\rho^0 \to \pi^+\pi^-$ 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 $B^0 \to J/\psi K_0^*(1430)^+\pi^-$. If these events are due to $B^0 \to J/\psi K_S^0 \rho^0$ and there is no interference with the $B^0 \to J/\psi K^{*+}\pi^-$ contribution, this corresponds to a branching ratio of:

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

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

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 $\mathrm{BR}(B^+ \to J/\psi K^+\pi^+\pi^-) = (1.2 \pm 0.3 \pm 0.2) \times 10^{-3}$; $\mathrm{BR}(B^+ \to \chi_c K^+) = (10.4 \pm 3.6 \pm 1.6) \times 10^{-4}$; $\mathrm{BR}(B^0 \to J/\psi K^{*0}\pi^+\pi^-) = (5.3 \pm 1.1^{+0.8}_{-0.9}) \times 10^{-4}$; $\mathrm{BR}(B_s \to J/\psi \bar{K}^{*0}) < 8.5 \times 10^{-5}$; and a search for $B_s \to J/\psi K^{(*)0}\bar{K}^{(*)0}$.

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 essense 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 BTeV 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)
$B^0 \to K^{*0}\gamma$	1.1×10^{-4}
$B_s \to \phi\gamma$	1.2×10^{-4}
$B_s \to \mu^+\mu^-\phi$	4.2×10^{-5}
$B^+ \to \mu^+\mu^-K^+$	5.2×10^{-6}
$B^0 \to \mu^+\mu^-K^{*0}$	4.0×10^{-6}
$B^0 \to \mu^+\mu^-$	8.6×10^{-7}
$B_s \to \mu^+\mu^-$	2.6×10^{-6}

Table 1: CDF rare B decay limits.

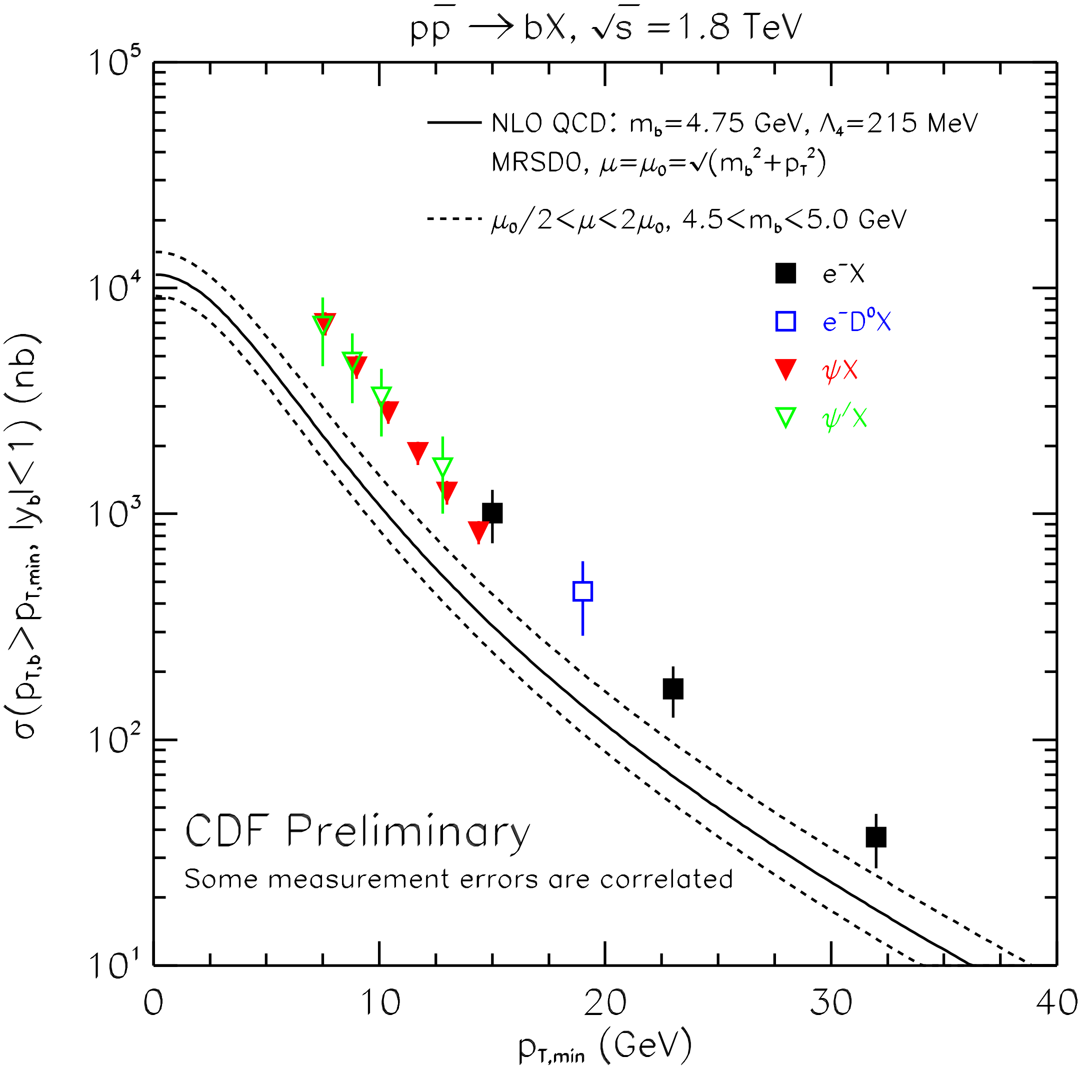

Figure 1: b differential production cross section at $\sqrt{s} = 1.8$ TeV.

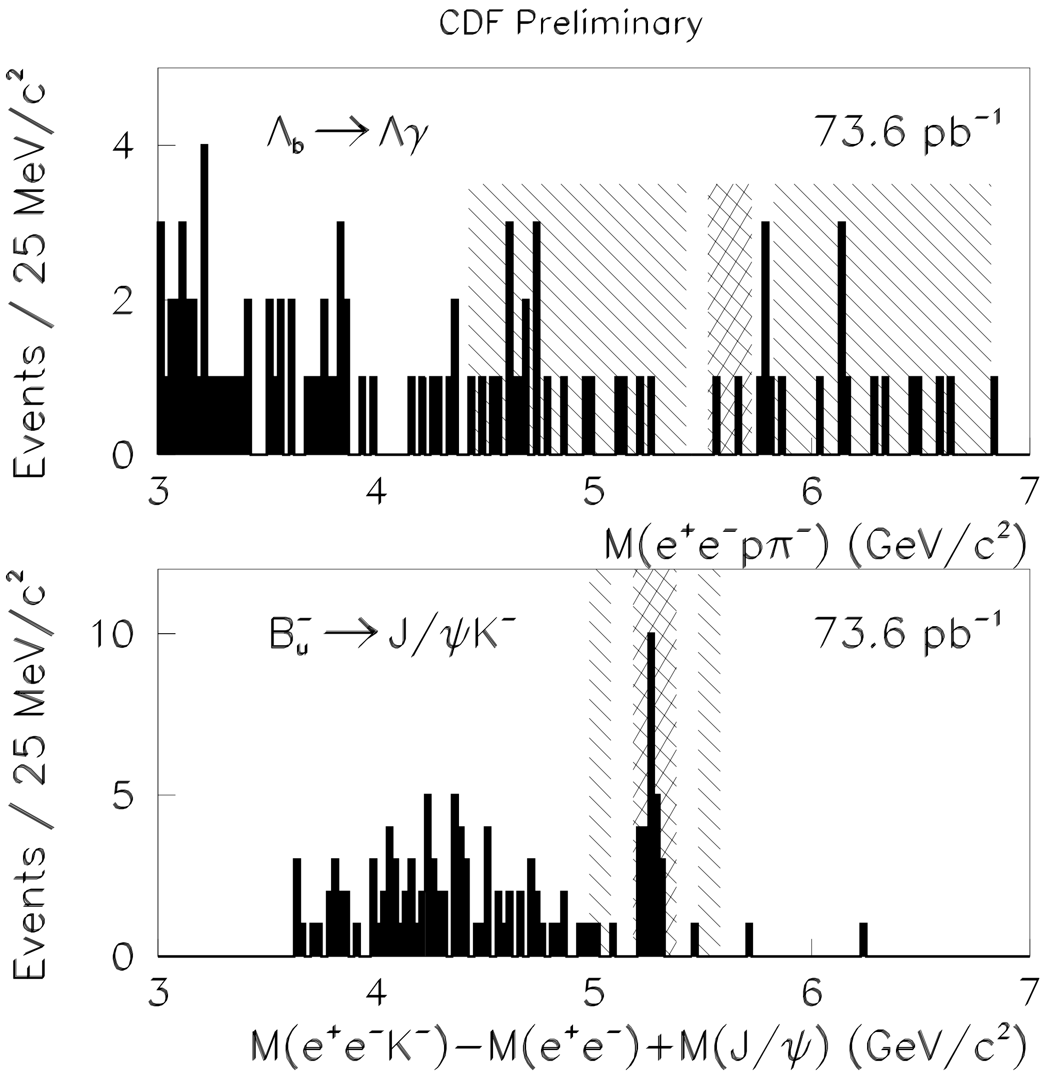

Figure 2: $\Lambda_b \to \Lambda\gamma$ candidates (top) compared to the $B^- \to J/\psi(\to e^+e^-)K^-$ reference signal (bottom).

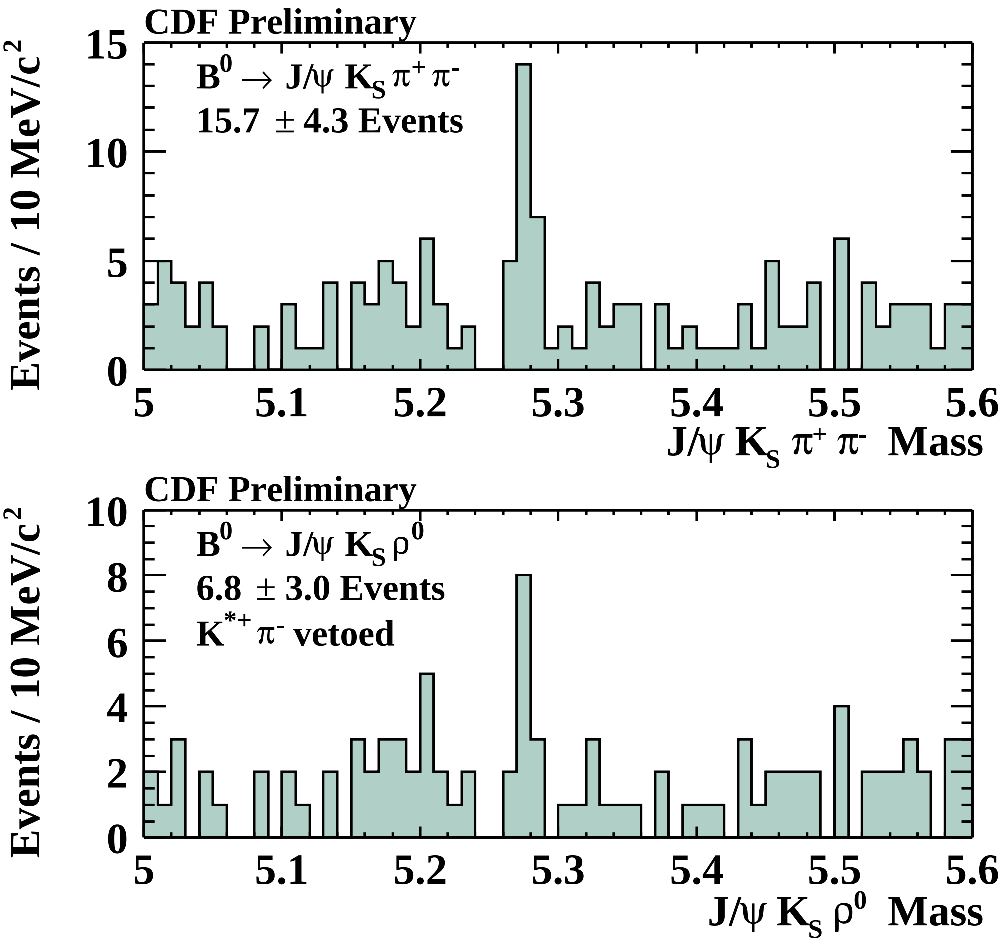

Figure 3: $B^0 \rightarrow J/\psi K^0_S \pi^+\pi^-$ candidate mass peak (top) with 15.7 ± 4.3 events. The bottom plot shows the $B^0 \rightarrow J/\psi K^0_S \rho^0$ events remaining after $B^0 \rightarrow J/\psi K^{*+}\pi^-$ candidates have been removed.