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UPDATE OF RUN 1 B RESULTS AT CDF

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Abstract

While the Collider Detector at Fermilab (CDF) is starting a new data run, it is also finishing analyses based on the 100 pb^{-1} "Run 1" data sample collected between 1992 and 1996. In particular, the Λ_b lifetime has been measured using the exclusive decay channel $\Lambda_b \rightarrow J/\psi\Lambda^0$. The B^+ cross section, based upon the decay $B^+ \rightarrow J/\psi K^+$, has been finalized, as well as the ratio of inclusive b quark cross sections at $\sqrt{s} = 630$ GeV and 1800 GeV. Early results from the new data run with the displaced-track trigger, which shows great promise for b physics at CDF, are presented.

1 Introduction

The Collider Detector at Fermilab (CDF) has pursued a vigorous research program into the physics of the b quark since accumulating its first significant data sample in 1988-89. This program has yielded a rich harvest in Run 1, which extended from 1992 to 1996 and accumulated about 100 pb^{-1}, including measurements of cross sections of both open b hadrons and bottomonium, lifetimes, masses, polarizations, and mixing asymmetries. The CDF data sample includes the world's largest samples of exclusive B_s and Λ_b decays, and it also yielded the first significant measurement of the CP asymmetry parameter $\sin 2\beta$ using the decay $B^0/\overline{B}^0 \to J/\psi K^0_S$ [1].

With the beginning of Run 2, which promises to deliver 2 pb^{-1} by 2004, CDF enters a new phase. At the same time, the harvest of b physics in the Run 1 sample continues to be exploited while other results are cast into their final form. In this article, a few recent results are highlighted which have bearing on lingering apparent discrepancies between experimental results and theoretical expectations.

2 Exclusive Λ_b Lifetime

The lifetime of the Λ_b is a subject of continuing interest, since the world average of its lifetime, $1.229^{+0.081}_{-0.079}$ ps, is only $(80 \pm 5)\%$ of the B^0 lifetime [2], in apparent disagreement with the theoretical expectation that all the b hadron lifetimes should be within 10% of one another [3]. The world average is based entirely upon inclusive semileptonic decay results, including one from CDF [4]. The lifetime has now also been measured using a sample of 38 ± 11 fully reconstructed $\Lambda_b \to J/\psi \Lambda^0$ events. The mass and proper lifetime distributions are shown in Figure 1 with the simultaneous mass and lifetime fit superimposed. The fit gives a lifetime of $1.22 \pm 0.36(stat) \pm 0.033(syst)$ ps. The measurement uncertainty is clearly dominated by the small sample size.

This result is the first Λ_b lifetime measurement using a fully reconstructed decay channel. While it is not by itself competitive with other Λ_b lifetime measurements, it also suffers less from systematic uncertainties which are inherent in the inclusive semileptonic channels studied before. Moreover, most of the systematic effects such as the background shape can reasonably be expected to decrease as larger samples are studied. It is projected that a large sample of Λ_b decays, many of them fully reconstructed, will be collected at CDF in the next few years. The expected precision, ± 0.04 ps, of a lifetime measurement with $J/\psi \Lambda^0$ alone is better than the current world average, and in combination with that from semileptonic

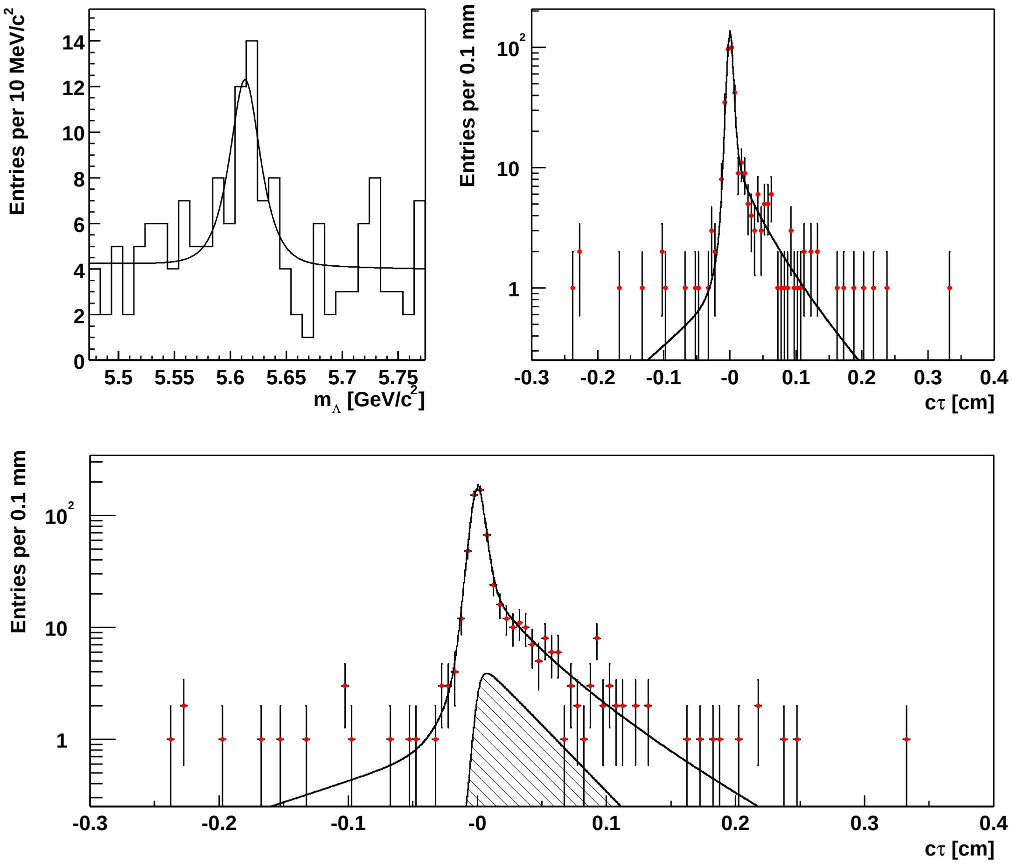

Figure 1: *Top left:* $J/\psi\Lambda^0$ *mass distribution. Top right: sideband proper time distribution with background fit result superimposed. Bottom: signal proper time distribution with fit superimposed. The* Λ_b *signal component is shown hatched.*

decays, should help resolve the apparent discrepancy in b baryon lifetimes.

3 B Production

The first cross section results for the production of b hadrons were published as integrated b quark cross sections as a function of b quark p_T^{min}, which was conventionally defined as the minimum p_T at which 90% of the resulting hadrons passed a given set of kinematic requirements. This approach to presenting the results had the advantage of making the best use of the small samples available, and also allowing experiments to utilize inclusive signatures which yielded the largest samples; the UA1 result at $\sqrt{s} = 630$ GeV was based upon high-p_T dimuons and agreed well with next-to-leading order (NLO) calculations [5]. The disadvantage of the method was that it required the convolution of non-perturbative effects such as the hadronization of the b quark into hadrons, which had a direct impact on the overall scale of the measured cross sections.

Early CDF publications of the absolute b quark cross section followed the convention of quoting integrated quark cross sections but found the measured cross sections to exceed those initially anticipated from NLO theory and Peterson fragmentation. Recent CDF results, using the larger samples collected in Run 1, tend to simplify the analysis techniques and to quote numbers closer to the experimental observables in order to reduce model dependence. Differential cross sections are also preferred for the same reason. The overall conclusion, however, remains the same: the cross sections at $\sqrt{s} = 1800$ GeV are significantly larger than original expectations.

CDF has also published a ratio of b quark cross sections between 630 GeV and 1800 GeV, which is described in Section 3.2. Many systematic uncertainties cancel in the ratio, reducing the theoretical uncertainty from a factor of two for absolute cross sections to approximately 15%. The ratio is also potentially sensitive to new physics: some have suggested that the large discrepancy in the absolute cross section could indicate light gluino production and decay into b quarks and squarks [6], while others have pointed to less exotic explanations such as inadequate understanding of the fragmentation process [7]. Unfortunately, the relative enhancement of the cross section due to possible gluino decay at the higher energy is of the same order as the current theoretical uncertainty on the QCD prediction of the ratio.

3.1 Exclusive B^+ Cross Section

The B^+ cross section measurement is based upon full reconstruction of $B^\pm \to J/\psi K^\pm$ decays in 98 ± 4 pb^{-1} of data [8]. The decays are reconstructed in the silicon microstrip detector (SVX) so as to take advantage of its flight distance resolution, and the background is suppressed by requiring the proper time $ct > 100$ μm. The resulting yield is 387 ± 32 events split up into four B^+ p_T bins starting at 6 GeV/c. The differential p_T spectrum is shown in Figure 2(left). The largest systematic uncertainty common to all four points, $\pm 10\%$, comes from the branching fractions of $B^+ \to J/\psi K^+$ and $J/\psi \to \mu\mu$, while the luminosity determination contributes $\pm 4.5\%$. The largest uncorrelated systematic uncertainty, less than about $\pm 3\%$ in each p_T bin, comes from the trigger efficiency. The QCD renormalization and fragmentation uncertainties, which may change the p_T shape within a single bin, contribute less than $\pm 2\%$ each in each bin.

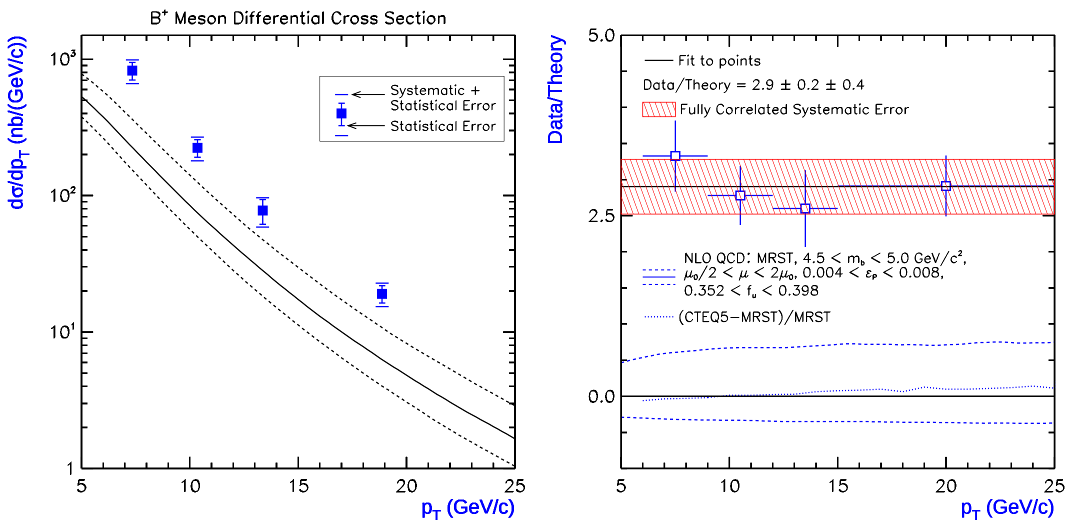

Figure 2: *Left: the B^+ differential cross section compared to theory. Right: the ratio of the measured differential cross section and theory.*

The total cross section for B^+ meson $p_T > 6$ GeV$/c$ and $|y| < 1$ is $3.6 \pm 0.4 \pm 0.4$ μb, where the first error is statistical combined with the uncorrelated systematic, and the second is from the fully correlated systematic uncertainty. This final number is higher than previous results partly due to using more recent branching fraction measurements [9] and better luminosity determination. This analysis also relies more upon the data, and less upon simulation, to assess efficiencies and luminosities than previous analyses.

The comparison between the measured cross sections and theory shown in Figure 2(right) is done with NLO theory and MRST parton distribution functions, followed by Peterson fragmentation with $\epsilon = 0.006$. While the shapes are indistinguishable, the discrepancy in the absolute normalization is striking: the ratio between data and theory is $2.9 \pm 0.2 \pm 0.4$, where again the first uncertainty is from the statistical and uncorrelated systematic uncertainties in each bin, and the second is from the fully correlated systematic uncertainties including those from the branching fractions and luminosity determination. As noted above, however, recent discussions have suggested that the discrepancy is not nearly so dramatic with better characterization of the fragmentation process.

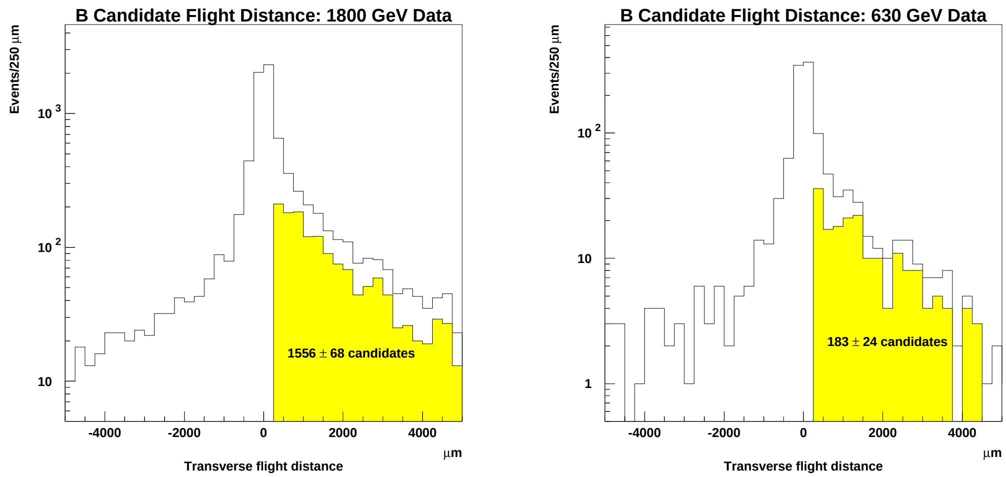

Figure 3: *L_{xy} distributions for* $\sqrt{s} = 1800$ GeV *(left) and* 630 GeV *(right). The shaded regions indicate the long-lived excess.*

3.2 Cross Sections at 630 and 1800 GeV

The ratio of b quark cross sections at $\sqrt{s} = 630$ GeV and 1800 GeV has been measured at CDF using a short run of 582 ± 24 nb^{-1} taken over 9 days in 1995 at the lower energy and compared with 623 ± 30 nb^{-1} of 1800 GeV data immediately before and after [10]. With these small samples, an inclusive method involving a muon combined with a high-p_T track is used to identify b candidates; the p_T^{min} is calculated to be 10.75 GeV/c. The invariant mass of the track pair is required to exceed 1.5 GeV/c to remove charm. The track pair flight distance L_{xy} in the plane transverse to the beam is then used to separate b events from backgrounds: the number of b's is proportional to the number of events with $L_{xy} > 250$ μm less those with $L_{xy} < -250$ μm. The L_{xy} distributions are shown in Figure 3. The shaded regions indicate the b component of the distributions. Correcting for the relative acceptances of b events at the different energies, the cross section ratio for $p_T^{min} =$ 10.75 GeV/c is found to be $\sigma_b^{630}/\sigma_b^{1800} = 0.171 \pm 0.024(stat) \pm 0.012(syst)$, where the largest systematic uncertainty comes from the ratio of integrated luminosities used in the analysis.

The measured cross section ratio agrees well with NLO QCD with MRST parton distribution functions as shown in Figure 4(left). Since the cross section ratio agrees so well with theory, it should come as no surprise that when this result is combined with CDF measurements at $\sqrt{s} = 1800$ GeV to produce an absolute cross

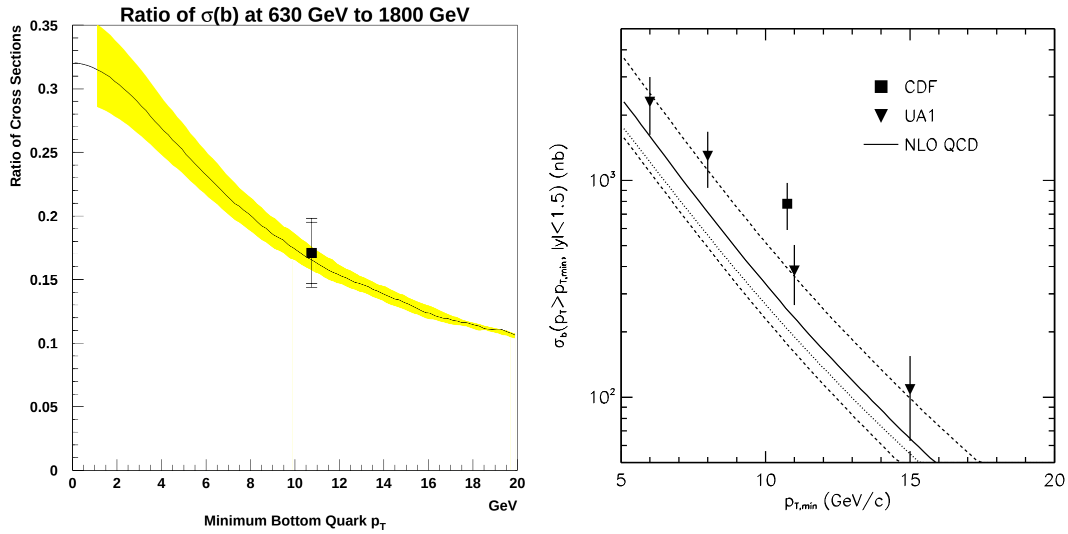

Figure 4: *Left: comparison of the ratio of integrated b quark cross sections to theory. Right: comparison of the integrated cross section to UA1 results and to NLO theory at* $\sqrt{s} = 630$ GeV.

section at the lower energy, that absolute cross section should also be higher than the theory. The result is shown in Figure 4(right), along with the published UA1 numbers. The CDF number is in fact the best b quark cross section measurement at 630 GeV in spite of the small sample by Run 1 standards. The disagreement with the UA1 results is at a confidence level less than 95%.

4 Looking Forward to Run 2

The Fermilab Tevatron has begun to deliver collisions at $\sqrt{s} = 1960$ GeV for Run 2, and CDF has received several major upgrades in order to take advantage of the increased luminosity. These upgrades are covered in more detail by S. Rolli [11]. In the area of b physics, the most important upgrade is the Silicon Vertex Trigger (SVT) coupled with the deadtimeless, pipelined trigger system. This trigger system allows the detector to select, in real time, events with large impact parameters, a generic feature of b decays. This new capability allows CDF to collect large samples of fully hadronic decays such as $B^0 \to \pi^+\pi^-$ and $B_s \to (D_s \to \phi\pi)\pi$. An early indication of the ability of this trigger system to select heavy flavor events is shown in Figure 5(left), which is the L_{xy} distribution of pairs of tracks using only parameters calculated by the SVT in a small 15 nb^{-1} sample. Much like the b cross

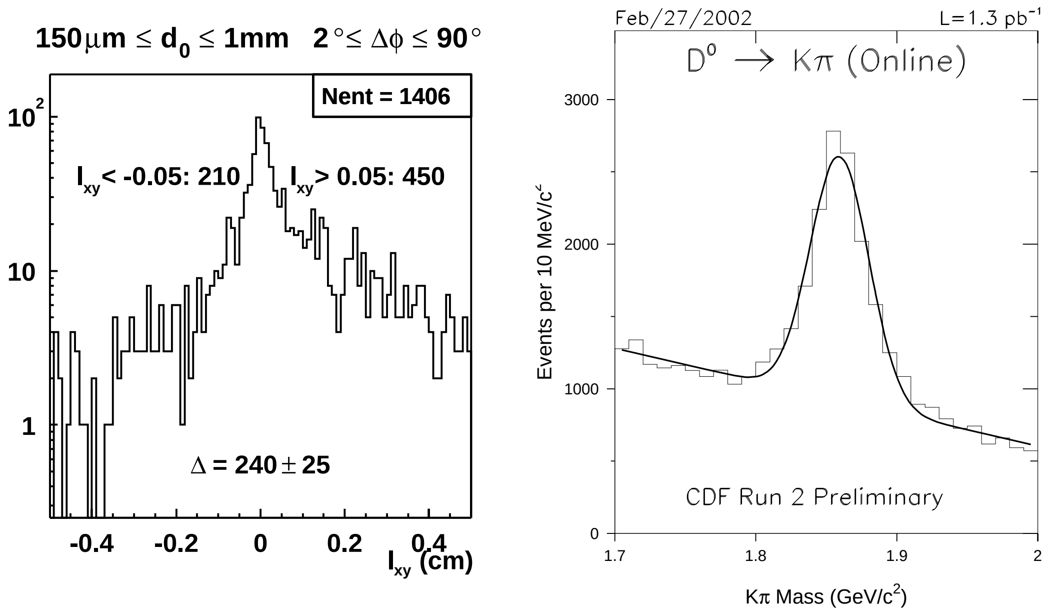

Figure 5: *Online distributions from the displaced-track trigger. Left:* L_{xy} *distribution, showing the positive lifetime bias characteristic of heavy flavor production. Right:* $D^0 \to K\pi$*, as reconstructed using only online quantities.*

section ratio analysis, the background events pile up around $L_{xy} = 0$, while heavy flavor populates $L_{xy} > 0$. The positive bias is very evident even in this small sample. Figure 5(right) shows the $K\pi$ mass distribution of track pairs in 1.3 pb^{-1} and a very clear $D^0 \to K\pi$ peak, again using track parameters calculated by the online system.

With a modest amount of data, it is straightforward to reconstruct large charm samples, as shown in Figure 6. The $D_s \to \phi\pi$ mode is particularly interesting, since it represents the first step toward reconstructing the fully hadronic B_s decay to $D_s\pi(\pi\pi)$ which is an important part of the CDF program to observe B_s flavor oscillation. In fact, large samples of fully reconstructed c and b hadrons will also significantly enhance the capabilities of CDF in pursuing other CKM-related measurements as well as production studies of heavy flavor hadrons and their excited states.

5 Conclusion

Even while Run 2 begins, the physics of the Run 1 data sample at CDF is still being exploited. One result is the first Λ_b lifetime measured using a fully reconstructed

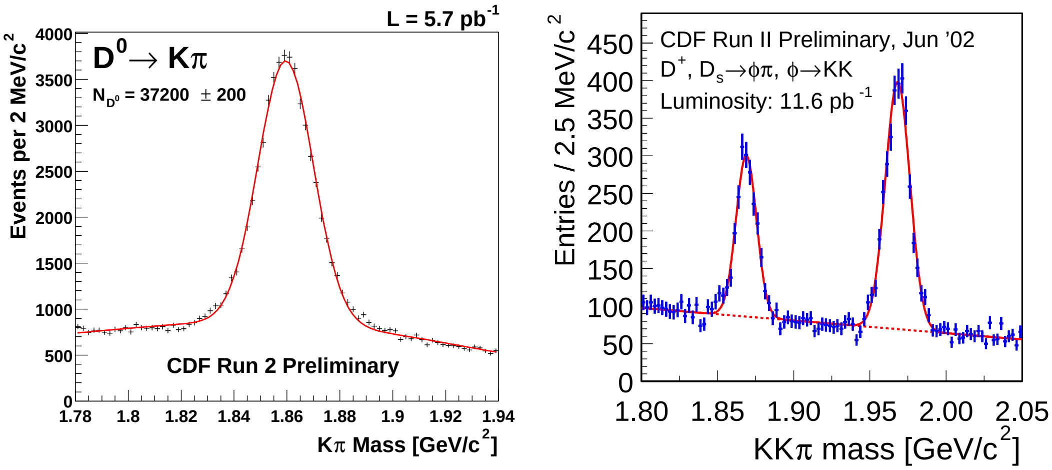

Figure 6: $D^0 \to K\pi$ *(left), and* D^+ *and* $D_s \to \phi\pi$ *with* $\phi \to KK$ *(right) reconstructed in data selected with the displaced-track trigger.*

decay channel. In addition, production cross section studies have been finalized and show the same patterns as before: the measured cross section is higher than initially anticipated, and the ratio of cross sections at $\sqrt{s} = 630$ GeV and 1800 GeV agrees with the theoretical expectation. Recent theoretical discussions may resolve the picture, or at least suggest some more handles with which to differentiate between some of the hypotheses advanced. This work will profit from the enhanced capabilities of CDF and the Tevatron in Run 2.

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