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Beauty production at CDF

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A review of recent measurements of beauty production, based on proton antiproton collision data at $\sqrt{s} = 1.96$ TeV and using the CDF detector, is given.

1 Introduction

Previous measurements of beauty (b) quark production at the Tevatron, carried out at centre-of-mass energies $\sqrt{s} = 1.8$ TeV, have shown discrepancies when compared to Next to Leading Order (NLO) predictions [1]. Improved predictions and experimental procedures have reduced this discrepancy [2]. Improved parton density functions, better fragmentation functions and more complete theoretical calculations have improved theoretical accuracy. Experimentally, measurements of beauty production at $\sqrt{s} = 1.96$ TeV are now presented in terms of b hadrons or B mesons, to avoid problems unfolding back to the quark level.

In this review [3] measurements of inclusive beauty (where one beauty jet or hadron is reconstructed in the event), and beauty + X (where X can be a boson or another beauty jet or hadron), production will be presented: inclusive beauty jet cross-section; semi and fully reconstructed B meson cross-section; beauty dijet cross-section; semi-reconstructed B $\overline{\mathrm{B}}$ meson cross-section; Z boson + beauty jet cross-section. More information concerning other measurements of heavy quark production can be found elsewhere [4].

2 Inclusive measurements

In this section measurements of inclusive b jet production, and semi and fully reconstructed B meson production, will be discussed.

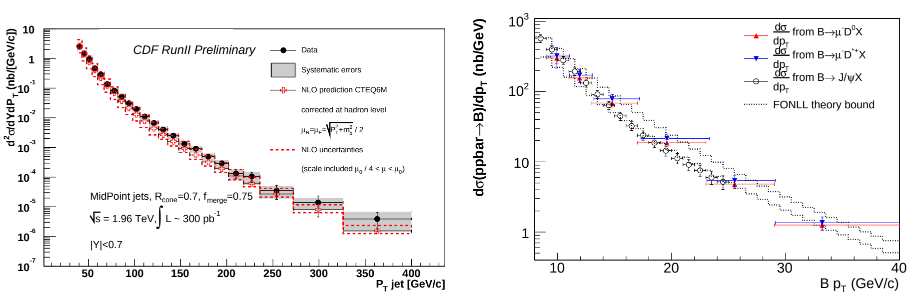

Figure 1: Differential cross-sections for (left) b jet production as a function of jet transverse momentum (Pt), and (right) semi-reconstructed b hadron production as a function of hadron Pt. In both cases the data are shown as points, compared to NLO predictions (histograms).

CDF have analysed 300 pb^{-1} of data to measure the inclusive beauty jet cross-section. The data are collected by a jet-based trigger. Jets are identified within a pseudorapidity region $|\eta| < 0.7$, using the Midpoint [5] cone algorithm with a radius of 0.7 and merging parameter $f_{merge} = 0.75$. Only jets of transverse energy (Et) between 38 and 400 GeV are considered in the analysis. Beauty jet candidates must also have a separated secondary vertex. The purity of the jets is determined by fitting the invariant mass of jets composing the secondary vertex to templates, obtained from Monte Carlo simulation, of the masses expected for beauty, charm and light jets. The differential cross-section, shown in figure 1, is consistent with NLO prediction [6]. Precision is dominated by the large systematic error arising from the jet energy correction, which introduces a 20-40% uncertainty dependant on jet Et.

A more precise experimental measurement of b production can be obtained by measuring beauty hadrons, rather than jets. In this way uncertainty due to the jet energy scale can be avoided. CDF has performed two analyses in this way. The first semi-reconstructs B hadrons through their semi-leptonic decays to a muon and a charm meson which subsequently decays to $K^{-}\pi^{+}$. A displaced track plus lepton trigger is used to collect 83 pb^{-1} of data to perform the analysis. Beauty hadrons are reconstructed within $|\eta| < 0.6$, and must have a transverse momentum exceeding 9 GeV. The purity of the selected events is determined by fitting the invariant mass of the reconstructed charm meson to a Gaussian signal and polynomial background. The effects of residual prompt charm are estimated by fitting the impact parameter of the reconstructed events, and like sign muon-pion pairs are counted to estimate the impact of $B \longrightarrow DX + B \longrightarrow \mu X$ decays mimicing a signal. The differential cross-section is shown in figure 1 as a function of hadron Pt and agrees well with Fixed Order Next to Leading Log (FONLL) [7] predictions. Systematic errors are small, and dominated by luminosity (6%).

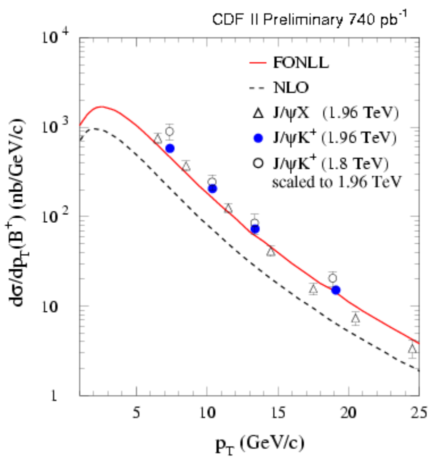

Figure 2: The differential cross-section for B^{+} meson production, shown as a function of hadron Pt. The data are shown as points, and are compared to FONLL prediction. Note that previous published measurements, taken at a lower centre-of-mass energy and scaled appropriately, are overlaid. The dotted line shows an old NLO prediction, which should be disregarded.

The second measurement identifies a B meson by fully reconstructing the decay $B^{+} \longrightarrow J/\psi K^{+}$. A J/$\psi$ trigger is used to collect a dataset of 740 pb^{-1}. Reconstructed mesons must have a transverse momentum of at least 6 GeV within $|\eta| < 1$. The purity of selected events is determined by fitted the reconstucted meson mass. The differential cross-section (shown in figure 2), is compared to FONLL predictions and is consistent [8]. Systematic errors are small, and dominated by the luminosity uncertainty (6%).

3 Beauty + X measurements

CDF have performed studies of beauty production where both quarks in the event are reconstructed, and where one beauty quark is produced in association with a gauge boson.

Events containing both beauty quarks in the event preferentially test LO contributions to the cross-section. Events containing one beauty quark and a Z boson provide sensitivity to the b quark content of the proton.

The first measurement determines the beauty dijet cross-section. Events are obtained using a displaced track trigger, and some 260 pb^{-1} of data are analysed. Jets are defined using a cone algorithm with a radius of 0.4. Candidate events must have two jets within $|\ \eta\ | < 1.2$. The highest (next highest) Et jet must have a transverse energy exceeding 35 (32) GeV. Beauty jets are selected by identifying a separated secondary vertex within the jet. The purity of the selection is determined by fitting the invariant mass of tracks forming the secondary vertex to template shapes, as before. The cross-section is compared to MC@NLO [9] (CTEQ6M [10]) predictions, which use JIMMY [11] to model the underlying event, as well as Pythia [12] and Herwig [13] LO predictions. This topology preferentially picks out the leading order contributions to b production, as can be seen by the good agreement with LO Monte Carlo. It is only at small quark jet angles, where NLO contributions become important, that MC@NLO provides a better description (as shown in figure 3). Systematic errors are typically 20%, and are dominated by the uncertainty on jet energy scale.

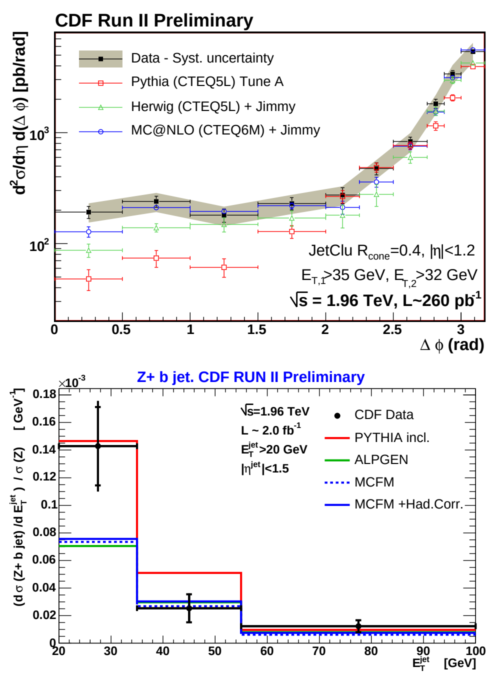

Figure 3: Differential cross-sections for (top) b dijet production, shown as a function of the azimuthal angle between jets, and (bottom) Z + beauty jet production, shown as a function of jet Et. The data are represented by points, and theoretical predictions are overlaid as symbols (top), and a histogram (bottom).

As with inclusive measurements, greater experimental precision can be obtained by reconstructing hadrons rather than jets. CDF have analysed 740 pb^{-1} of data obtained with a dimuon final state trigger. B hadrons are identified by reconstructing the semi-leptonic decay $B \to \mu^- X, \overline{B} \to \mu^+ X$. The muons are identified using standard requirements and must have a transverse momentum greater than 3 GeV. The dimuon pair must have a transverse momentum exceeding 2 GeV, and an invariant mass between 5 and 80 GeV. Purity is estimated by a fit to both muon track impact parameters in data, to templates of the shapes expected for beauty, charm and light tracks. The measured cross-section $(1549 \pm 133\ \text{pb})$ is subject to a small systematic error, dominated by luminosity at 6%, and is consistent with NLO predictions [14] $(1293 \pm 201\ \text{pb})$.

Finally, the cross-section for beauty jets produced in conjunction with a Z^0 boson has been measured with 2 fb^{-1} of data. This mode is sensitive to NLO production mechanisms and provides some sensitivity to the beauty quark content of the proton. Events are triggered on high invariant mass electron positron (dimuon) pairs, within $|\ \eta\ | < 2.5$ ($|\ \eta\ | < 1.5$). Jets are identified using a cone algorithm, of radius 0.7,

and must have transverse energy above 20
GeV, lie within $| \eta | < 1.5$ and have a separated secondary vertex. The purity is determined by fitting the invariant mass of tracks composing the secondary vertex, as before. Further details of the analysis can be found in [15]. The resultant cross-section, which is also presented as the ratio of Z+ beauty jet to Z production, is compared to LO (Pythia, Alpgen [16], Herwig) and NLO (MCFM [17] + CTEQ6M) predictions. Systematic errors are at the level of 14% and are dominated by transverse energy modelling (8%) and luminosity (6%). Differential cross-section distributions, one of which is shown in figure 3, are most similar to Pythia predictions. NLO predictions are a factor two smaller than data, although this difference (1.7 standard deviations) is not significant.

4 Conclusions

Measurements of beauty production at CDF have been presented. In all cases experimental results agree with theoretical (NLO) predictions.

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