HEAVY FLAVOR PRODUCTION AT THE TEVATRON

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Results on inclusive b-jet production, $Z + b$-jet production, and b-jet production from $W + b\bar{b}$ process at the Tevatron are presented.

1. Inclusive b-jet production

Measurements on b-quark production at the Tevatron provide an important test of perturbative Quantum Chromodynamics (QCD). The observed mismatch between the Tevatron Run 1 measurements and theoretical predictions has motivated further effort to improve both experimental measurements and theoretical predictions and widen the scope of the observables. Recent results on B hadron production cross section measurements in Run 2 show reasonable agreement with theoretical predictions [1].

Here, a recent measurement of the inclusive b-jet cross section performed by CDF is presented. A b-jet is defined as any jet that has at least one B hadron within the jet. This measurement used about 300 pb^{-1} of data collected with five trigger paths requiring jets and/or calorimeter trigger towers above certain E_T thresholds. Jets are reconstructed using the Midpoint algorithm, an iterative cone clustering algorithm. Jet energies measured by the calorimeter are corrected for energy from additional $p\bar{p}$ interactions in the same bunch crossing (pile-up) and detector effects. The detector response correction is determined from Pythia Tune A [2] dijet Monte Carlo (MC) samples by matching jets at the hadron level and calorimeter level and using their correlation in p_T. The calorimeter simulation used to generate the MC samples is tuned to reproduce the real CDF calorimeter's response to individual particles measured in the test-beam and in-situ data [3].

b-jets are "tagged" by the presence of a displaced secondary vertex within the jet arising from the decay of the long-lived B hadron. The b-tagged event sample includes background contributions from charm, light-quark and gluon jets. The fraction of b-jets in the b-tagged sample is evaluated by performing a fit to the invariant mass of all charged tracks attached to the secondary vertex; on average, b-jets have a larger secondary vertex mass than c-jets and light-flavor jets due to the larger B hadron masses. The obtained b-jet fraction in the b-tagged sample is 0.35±0.07 at $p_T^{jet} = 38$ GeV/c and 0.14±0.08 at $p_T^{jet} > 250$ GeV/c.

The measured inclusive b-jet cross section is shown in Fig. 1 together with the next-to-leading (NLO) QCD prediction [5]. The ratio of the data over the NLO QCD prediction is also shown. The NLO QCD prediction is computed with the renormalization and factorization scales (μ_R and μ_F) set to $\mu = \mu_0/2 = 1/2\sqrt{(p_T^{jet})^2 + m_b^2}$. The NLO QCD prediction is corrected for non-perturbative contributions from the underlying-event and hadronization as determined by Pythia Tune A. The major sources of the experimental uncertainty on the measurement are the uncertainty in the b-jet fraction in the b-tagged sample and the uncertainty in the jet energy scale. The largest source of the uncertainty on the prediction is its depen-

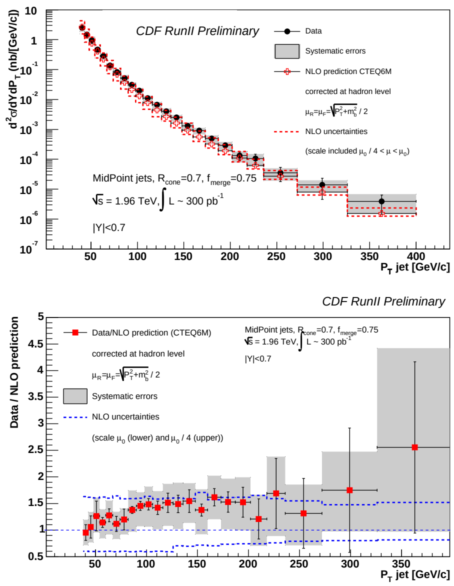

Fig. 1. (a) Measured inclusive b-jet differential cross section (filled circles) compared to the NLO QCD prediction (empty crosses). (b) The ratio of data/NLO QCD versus p_T^{jet}. Also shown are the experimental systematic uncertainties (shaded band) and the theoretical errors (dashed lines).

dence on μ_R and μ_F; a variation of μ_R and μ_F between μ_0 and $\mu_0/4$ changes the cross section by ± 40 % at low p_T^{jet} and ± 20 % at high p_T^{jet}. The measured b-jet cross section is consistent with the theoretical prediction, although the strong dependence on the choice of the renormalization and factorization scales in the QCD prediction indicates that higher-order contributions could play a major role.

CDF has also made a preliminary measurement on b-jet shapes in four p_T bins from 52 to 300 GeV/c using the 385 pb^{-1} of data. The measurement was made using the integrated jet shape variable:

$$\Psi(r) = \frac{1}{N_{jet}} \sum_{jets} \frac{p_T(0,r)}{p_T(0,R)}, \qquad 0 \le r \le R,$$

where R is the jet cone radius and $p_T(0,r)$ is the total p_T inside a sub-cone of radius r around the jet axis. Pythia predicts b-jets to be wider than inclusive jets as shown

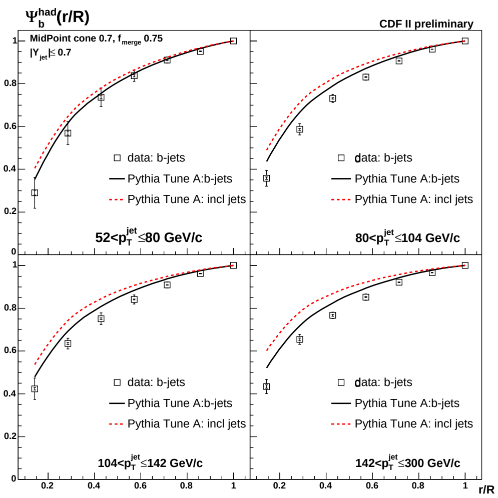

Fig. 2. The measured integrated b-jet shape, $\Psi(r/R)$, in four p_T^{jet} regions (open squares).

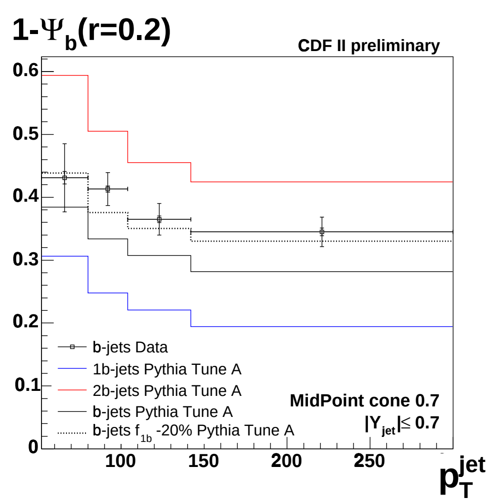

Fig. 3. The measured $1 - \Psi(0.2/R)$ versus p_T^{jet}.

in Fig. 2, and CDF measured that the b-jet shape is wider than the inclusive jet shape; however, the measured b-jet shape is poorly described by Pythia Tune A which describes jet shapes in inclusive jet production reasonably well [6]. As shown in Fig. 3, the b-jet shape has a non-negligible dependence on the number of b-quarks in the jet, and the data-Pythia agreement is reasonable when the fraction of jets containing only 1 b is decreased by ~ 20 %.

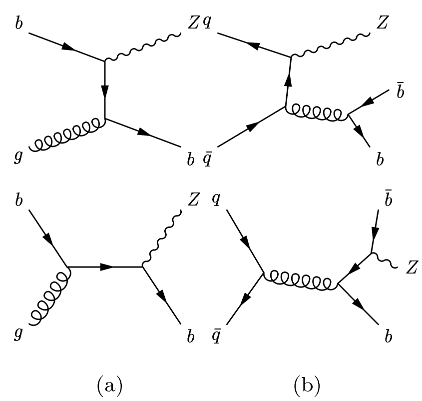

Fig. 4. Feynman diagrams contributing to Z+b production.

2. Z+b-jet production

The $Z + b$-jet production has been studied by the DØ and CDF collaborations. The dominant production diagrams contributing to the $Z + b$-jet final state are (a) $bg \to Zb$ and (b) $q\bar{q} \to Zb\bar{b}$ (see Fig. 4): in NLO calculations, they contribute about 65% and 35% respectively. The cross section is sensitive to the b-quark density in the proton, and thus the measurement of the $Z + b$-jet cross section provides important information for constraining the b-quark density in the proton. A good understanding of the b density in the proton is essential to accurately predict the production of particles that couple strongly to b-quarks including supersymmetric Higgs bosons and single top production. $Z + b$-jet production is also a major background in searches for the standard model Higgs production in the $ZH \to Zb\bar{b}$ channel.

DØ used about 180 pb^{-1} of data [7] for the measurement. The Z candidates are selected from the di-electron and di-muon samples by requiring the di-electron (muon) mass to be within a Z-mass window. The Z+jet sample is then selected by requiring the presence of at least one reconstructed jet with $p_T > 20$ GeV/c and $|\eta| < 2.5$. The $Z + b$-jet events are then selected by requiring at least one jet tagged as a b-jet by the secondary vertex algorithm. The cross section ratio $\sigma(Z + b\text{-jets})/\sigma(Z + \text{jets})$ for jets with $p_T > 20$ GeV/c and $|\eta| < 2.5$ was measured to be:

$$\sigma(Z + b\text{-jets})/\sigma(Z + \text{jets})$$
$$= 0.021 \pm 0.004(\text{stat.}) + 0.002 - 0.003(\text{syst.}).$$

which is in agreement with the NLO QCD prediction of 1.8 ± 0.4 % calculated with MCFM [8].

CDF also performed a similar measurement using 330 pb^{-1} of data recently [9]. The cross section of b-jets with $E_T > 20$ GeV and $|\eta| < 1.5$ in events with a Z boson is measured to be:

$$\sigma(Z + b\text{-jets}) \times \mathcal{B}(Z \to l^+l^-)$$
$$= 0.93 \pm 0.29(\text{stat.}) \pm 0.21 \text{ pb}.$$

where $\mathcal{B}(Z \to l^+l^-)$ is the branching ratio of Z/γ^* into a di-electron or di-muon pair in the mass range of $66 < M_{ll} < 116$ GeV/c^2. The result is consistent with the NLO QCD prediction of 0.45 ± 0.07 pb calculated with MCFM. The cross section ratio $\sigma(Z + b\text{-jets})/\sigma(Z + \text{jets})$ in the same kinematic region is measured to be:

$$\sigma(Z + b\text{-jets})/\sigma(Z + \text{jets})$$
$$= 0.0236 \pm 0.0074(\text{stat.}) \pm 0.0053(\text{syst.}).$$

which is also in agreement with the Pythia estimate of 0.0218 and the NLO QCD calculation of 0.0181 ± 0.0027. The CDF measurement used a secondary vertex mass fit, similar to the one used described in Sec. 1, to determine the the b-jet fraction from the b-tagged sample without assuming the $Z + b$ to Z+c production ratio based on NLO QCD as done in the DØ measurement, and this approach resulted in the larger uncertainties.

3. W+$b\bar{b}$ production

CDF has made a preliminary measurement of the b-jet cross section for $W + b\bar{b}$ events (see Fig. 5). This measurement provides a test of the QCD calculations of the $W + b\bar{b}$

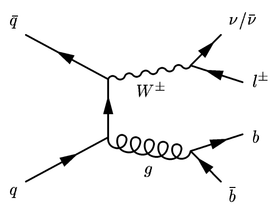

Fig. 5. Leading-order Feynman diagram for $W + b\bar{b}$ production.

cross section which is one of the major backgrounds in searches for the standard model Higgs boson and single top quark production.

This measurement is based on an integrated luminosity of 695 pb^{-1}. The data used in this measurement are selected from the inclusive electron and muon samples by requiring a reconstructed isolated electron $E_T > 20$ GeV or muon with $p_T > 20$ GeV/c, and missing transverse energy ≥ 25 GeV. After requiring one or two jets with $E_T > 20$ GeV and $|\eta| < 2$ and one or more jets tagged as b-jets by the secondary vertex algorithm, the data sample enriched with $W + b\bar{b}$ is obtained.

Even after the event selection cuts described above, a sizable number of events are expected to come from sources other than $W^{\pm}+b\bar{b}$ production. The largest background source is QCD multijet production in which there is no real W, but a combination of jets faking leptons, mismeasured jet energy, or semileptonic b-decay make the events pass through all the event selections. The other major background sources are $t\bar{t}$ production and single top quark production. The QCD multijet production contribution is evaluated using data, and the other background contributions are estimated from MC predictions.

The cross section for b-jets with $E_T > 20$ GeV and $|\eta| < 2$ from $W + b\bar{b}$ production is measured to be:

$$\sigma(W^{\pm}b\bar{b}) \times BR(W^{\pm} \to l^{\pm}\nu)$$
$$= 0.90 \pm 0.20(\mathrm{stat.}) \pm 0.26(\mathrm{syst.})\ \mathrm{pb}$$

which is in agreement with the Alpgen MC prediction of 0.74 ± 0.18 pb [11].

4. Conclusions

Various b-jet production processes have been studied at the Tevatron. CDF measured the inclusive b-jet cross section and found reasonable agreement with the NLO QCD prediction within uncertainties. CDF also made a preliminary measurement on b-jet shapes. Agreement of the measured b-jet shape with Pythia Tune A MC is reasonable if the fraction jets containing only one b-quark is decreased by $\sim 20\%$. Both DØ and CDF measured the ratio of $Z+b$-jet to $Z+$jet cross sections, and CDF also measured the $Z + b$-jet cross section. The results are consistent with the NLO QCD predictions within uncertainties. CDF made a preliminary measurement on b-jet cross section from $W + b\bar{b}$ production and found agreement with the Alpgen MC prediction.

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