$W^{\pm}/\ Z$ + JETS AND $W^{\pm}/\ Z$ + HEAVY FLAVOR JETS AT THE TEVATRON

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Studies of the production of $W^{\pm}/Z$ + jets are important for a variety of reasons. Herein the latest Tevatron results on these production mechanisms are reviewed with an emphasis on comparison of data results to the latest theoretical models.

1 Motivation

$W^{\pm}/Z$ + jets is a valuable sample for analysis at the Tevatron. Its high statistics allow one to probe the validity of predictions from perturbative Quantum Chromodynamics (pQCD). These processes play an important role in the Tevatron and LHC physics programs; $W^{\pm}/Z$ + inclusive jets will be a valuable standard model calibration sample at the LHC and $W^{\pm}/Z$ + heavy flavor are significant backgrounds to top, Higgs and other new physics searches at both the Tevatron and LHC. State-of-the-art leading order (LO) and next-to-leading order (NLO) calculations on these processes are the focus of several active theory collaborations. The predictions from these calculations would benefit from experimental verification.

Below are described important Tevatron results on $W^{\pm}/Z$ + inclusive jets, $W^{\pm}$ + single c and $W^{\pm}/Z$ + b-jets and how these results compare to available theoretical predictions.

2 $W^{\pm}$ + Jets and Z + Jets

The CDF experiment has studied the production of jets in events with $W^{\pm}$ and Z bosons [1,2]. $W \to e\nu$ events are selected by identifying a high E_T, central electron along with significant missing transverse energy, $\not\!\!E_T$; $Z \to e^+e^-$ events are selected by requiring one such electron with another that is either central or in the forward region of the calorimeter, with the invariant mass of the electron pair required to be near the Z mass peak. Events are then assigned to bins of minimum jet multiplicity. Major sources of background in the $W^{\pm}$+jets analysis include events with fake $W^{\pm}$'s and electroweak sources ($t\bar{t}$, single top, dibosons); backgrounds in the Z+jets analysis are dominated by multijet production and $W^{\pm}$+jets events in which the Z signal is faked. Acceptance for these events is studied using simulated signal samples; the differential cross section for the jets in these events is then examined and compared to some available theory predictions as depicted in Figure 1.

(a) (b)

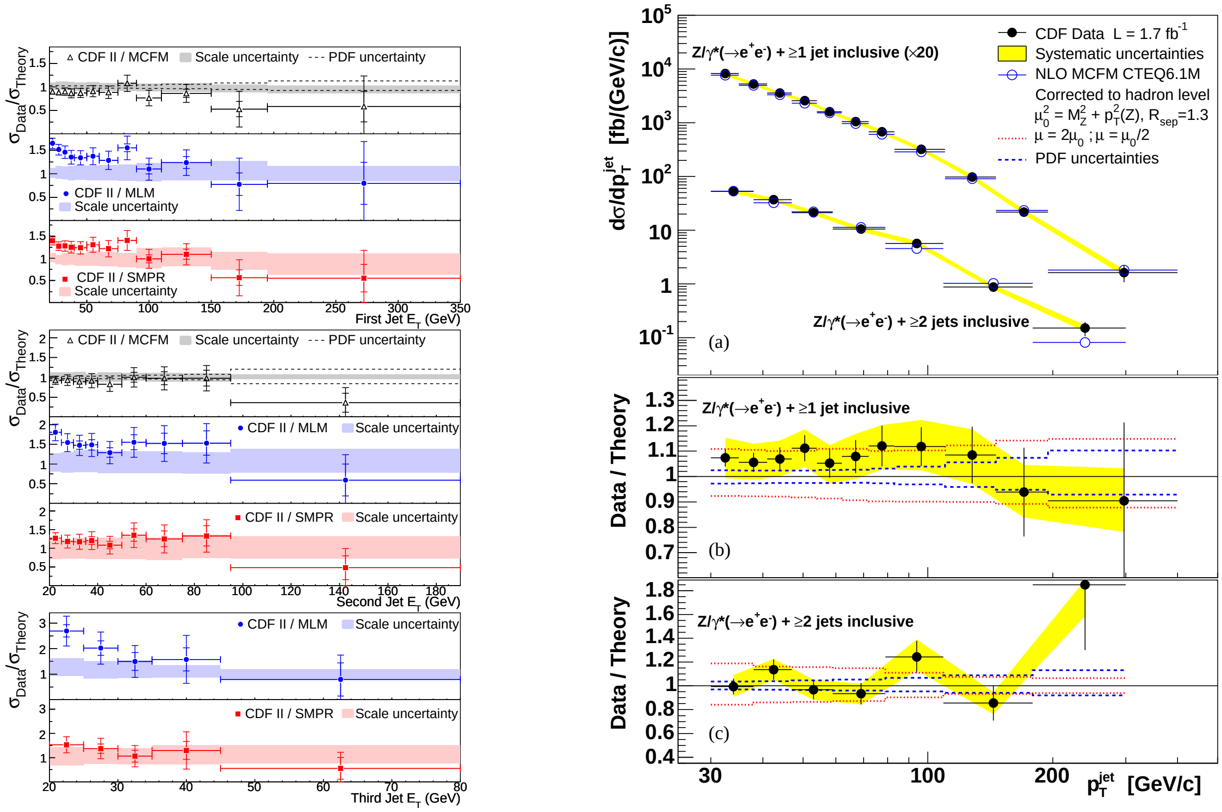

Figure 1: Differential cross section comparison of data and several theoretical predictions for (a) first, second and third jet E_T in $W^{\pm} + \geq 1$ jet events in 320 pb^{-1} of CDF Run II data and (b) jet p_T in $Z + \geq 1$ jet and $Z + \geq 2$ jets in 1.7 fb^{-1} of CDF Run II data.

From Figure 1(a) one can see that the NLO prediction from MCFM [3] is accurately reproducing the jet E_T spectrum in $W^{\pm}$+ 1 or 2 jets. For higher multiplicity events, LO calculations are necessary. The current preferred method for generating such events at LO relies on generating multiple samples using a matrix element calculation at fixed orders in α_s and then employing a parton shower program to add in additional soft, colinear jets. Matching algorithms have been designed to identify events that could be double counted in this recipe. From Figure 1 (a) one can see that the LO prediction consisting of the matrix element calculation from MadGraph [4], parton shower from Pythia [5] and matching scheme from CKKW [6] is superior to that of ALPGEN + Herwig shower + MLM-matching [7]. It remains to be understood which component of the prediction is causing the difference in these LO predictions. In Figure 1(b) one can see that the NLO prediction from MCFM accurately reproduces the jet p_T spectrum in Z+jets events, providing additional confirmation of the validity of the NLO predictions.

3 W+c

W+single-c production is an important process at the Tevatron. W+c offers insight on the strange content inside the proton. The process also allows an opportunity to measure $|V_{cs}|$ in a Q^2 regime not yet probed. Also, W+c contributes to the background to top production and prominent Higgs search channels at the Tevatron.

CDF [8] and DØ [9] have measured the W+c process in Run II using a similar strategy. Leptonic W decays ($W \rightarrow \ell\nu$ with $\ell = e$ or μ) are selected via a high p_T isolated central lepton and large $\not{E}_T$. Among the required jets in the selected events, evidence is sought for semileptonic hadron

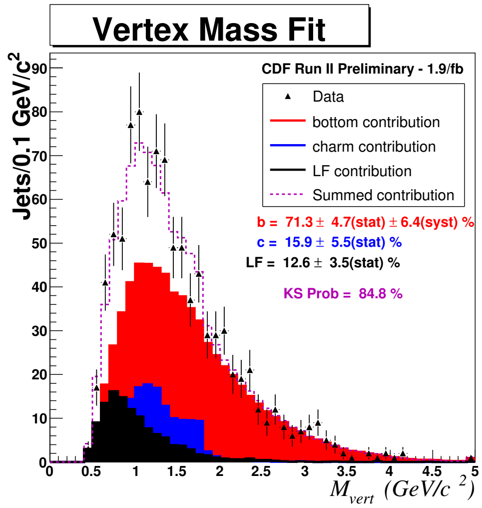

Figure 2: Vertex mass fit of tagged sample in CDF $W^{\pm}$ + b-jets analysis in 1.9 fb^{-1} of data.

decay through the identification of a soft muon inside the jet cone. It is a feature of W+c production that the electric charge of the W and c are opposite. The sign of the c quark is determined from the charge of the muon used to identify semileptonic hadron decay. An excess of opposite-sign primary lepton and soft muon events is indicative of W+c production. Opposite sign backgrounds include Drell-Yan production of $\mu^+\mu^-$, Wq production and fake W's.

CDF measured in 1.7 fb^{-1} of data the production cross section for W+c times the leptonic branching ratio of the W, $\sigma(Wc) \times \mathrm{BR}(W \to \ell\nu) = 9.8 \pm 2.8(\mathrm{stat})\ ^{+1.4}_{-1.6}\ (\mathrm{syst}) \pm 0.6(\mathrm{lum})$ pb for events with $p_T^c > 20$ GeV/c and $|\ \eta\ | < 1.5$. This can be compared to the NLO prediction from MCFM of 11.0 $^{+1.4}_{-3.0}$. DØ measured in 1 fb^{-1} of data the ratio $R = \frac{\sigma(Wc)}{\sigma(W+\mathrm{jets})}$; measuring the ratio has the virtue that numerous sources of systematic error cancel out. The result $R =$ 0.071 ± 0.017 is reasonably consistent with a LO prediction from ALPGEN of 0.040 ± 0.003.

4 $W^{\pm}$ + b-Jets and Z + b-Jets

$W^{\pm}/Z$+b jet signatures are important backgrounds to top and Higgs channels at the Tevatron. Separate analyses were undertaken to measure the b-jet cross section in $W^{\pm}$ and Z events with increased precision in the hopes of improving the understanding of these final states.

The event selection for the $W^{\pm}$+b jets analysis is similar to that employed in the W+c analysis discussed above. Here however b jets are selected via the identification of a secondary decay vertex well-separated from the primary $p\bar{p}$ interaction point. Among the jets possessing vertex tags, the b content is extracted via a maximum likelihood fit of the vertex mass, which is the invariant mass of the charged particle tracks comprising the secondary vertex. This variable is discriminant among the different species of jets; from Figure 2 one can see that among the tagged jets $\sim 71\%$ are found to be from b. Backgrounds to this $W^{\pm}$+b-jets signal include top production, diboson production and fake $W^{\pm}$'s. Signal acceptance was studied with simulated $W^{\pm}$+b-jet events using the ALPGEN event generator. Signal events are considered from a restricted region of phase space (e/μ with $p_T > 20$ GeV/c, $|\ \eta\ | < 1.1$, a neutrino with $p_T >$ 25 GeV/c and exactly 1 or 2 $E_T > 20$ GeV, $|\ \eta\ |< 2.0$ jets) to avoid strong dependence on the signal model in regions where we are not experimentally sensitive.

The b-jet cross section in $W^{\pm}$ events in 1.9 fb^{-1} of CDF Run II data was measured to be $\sigma_{b-\mathrm{jets}}(W + b-\mathrm{jets}) \times \mathrm{BR}(W \to \ell\nu) = 2.74 \pm 0.27(\mathrm{stat}) \pm 0.42(\mathrm{syst})$pb, where the systematic error is dominated by the uncertainty in the vertex mass shape one assumes for b jets. This jet

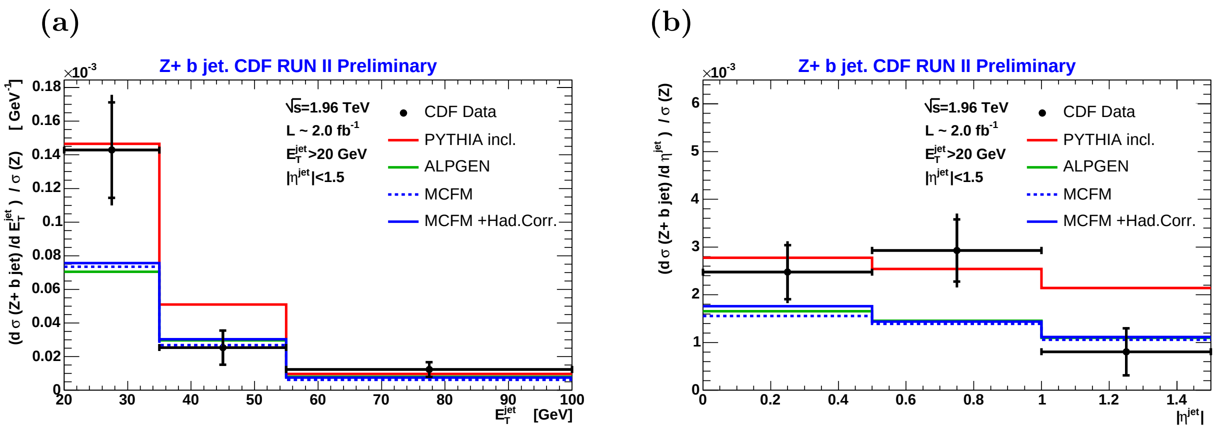

Figure 3: $Z + b$ jet differential cross sections as a function of jet p_T and $\mid \eta \mid$ from CDF's 2 fb^{-1} result.

cross section result can be compared to the prediction from ALPGEN of 0.78pb, a factor of 3-4 lower than what is observed in the data. Work is ongoing to understand the difference.

The Z+b-jet analysis used a similar technique to extract the b content of its tagged jet sample. This analysis has succeeded in examining differential cross sections for the b jets in Z events. From Figure 3 one can see that the differential b-jet cross sections versus jet p_T (a) and $\mid \eta \mid$ (b) are not reproduced in all bins by any of the predictions that were constructed. Pythia appears to do a reasonable job at low jet p_T but less so as the jet p_T increases. The ALPGEN and MCFM predictions are consistent with each other but not with the data except for a few bins. It remains to be understood why the predictions are so different.

5 Summary

The $W^{\pm}/Z$ + jets samples at the Tevatron offer a valuable high statistics testbed for state-of-the-art pQCD calculations. It appears that for inclusive jet production the NLO predictions are accurately describing the data for $W^{\pm}/Z$ + up to 2 jets. Predictions for higher parton multiplicity events at NLO would be beneficial. As for $W^{\pm}/Z$ + heavy flavor, NLO predictions for the integrated cross section for $W^{\pm}$+ single-c appear to be accurate. A consensus on $W^{\pm}/Z$ + b-jets has yet to be reached; both LO and NLO predictions do not consistently reproduce the integrated or differential rates of these events in the data.

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