PROCEEDINGS OF SCIENCE

Measurements of W/Z+jets production cross sections at the Tevatron

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We present measurements of inclusive $W/Z+n$ jet cross sections ($n = 1-4$), presented as total inclusive cross sections and differentially in the n^{th} jet transverse momentum and rapidity, as well as the heavy flavor content in these jets up to $n = 2$. The measurements are made using 4.2 to 6 fb^{-1} of data collected by the D0 detector at the Fermilab Tevatron Collider. The measurements are compared to next-to-leading order (NLO) perturbative QCD calculations.

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1. Introduction

The production of W and Z bosons in association with jets is a distinctive signature at hadron colliders and is of great importance. The measurement of these signatures and its properties allows for precision tests of perturbative QCD with particular emphasis on high jet multiplicity events where next-to-leading order (NLO) predictions have become available recently. Furthermore, for many measurements in Top quark or Electroweak physics and searches, e.g. for the Higgs boson and Supersymmetry, these processes constitute the dominant background which precise understanding is crucial for a successful search program. Finally, these processes also provide detailed benchmarks for tuning of parton shower (PS) and PS+matrix element matched Monte Carlo (MC) generators.

2. W + jets production

The inclusive cross sections of $W+n$-jet production have been measured in a p_T(jet) dependent way for jet multiplicities $n = 1-4$ using electrons with $p_T \geq 15$ GeV, $|\eta| \leq 1.1$, $\not{E}_{\mathrm{T}} \geq 20$ GeV, $M_T^W \geq 40$ GeV, p_T(jet ≥ 20 GeV and $|y| < 3.2$. Besides the inclusive cross section the ratio σ_n/σ_{n-1} for (for $N \in \{1,2,3,4\}$) has been determined. Use of the ratio leads to cancellation of uncertainties and increased precision. Additionally, the differential $W+(n)-$jet cross sections are measured as function of the n^{th} jet where the jets are ordered in p_T. The effects are fully corrected for the effect of finite experimental resolution, detector response, acceptance and efficiencies to the particle level. Details of to procedure and experimental results can be found in Ref. [1]. The unfolding is performed by using the GURU [2] unfolding program.

Figure 1 shows the resulting unfolded total cross section measurements of $W+(n)+jet$ production in the given phase space in comparison with two next-to-leading order (leading-order for $W+4$ jets) theoretical predictions using the MSTW2008PDF, and the σ_n/σ_{n-1} ratios. Fixed-order theoretical predictions provide results only at the parton-level so corrections for non-perturbative hadronization and underlying event effects are derived using default MPI and hadronization models implemented in SHERPA v1.2.3 MC generator and applied to the theory in order to allow for comparison to measured data.

Figure 2 shows the corrected differential cross sections of W+jets events, as a function of p_T(jet) for each of the four inclusive jet multiplicity bins studied. In order to reduce experimental uncertainties the measured differential cross-sections are normalized to the measured W jet inclusive cross-section. Comparisons are made to (N)LO *pQCD* predictions (again corrected for non-perturbative effects using SHERPA). Although the theoretical predictions are generally found to be in agreement with data, particular p_T regions show discrepancies.

2.1 Measurement of the $\sigma(Z+b)/\sigma(Z+jet)$ ratio

Measurement of the inclusive cross-section of Z boson production with at least one b-quark jet to the inclusive $Z+jets$ production cross-section has been performed using 4.2 fb^{-1}of data (Ref. [3]). Measuring the ratio to inclusive $Z+$jets allows again for partial cancellation of systematic uncertainties, providing a more precise measurement for comparison to theoretical predictions.

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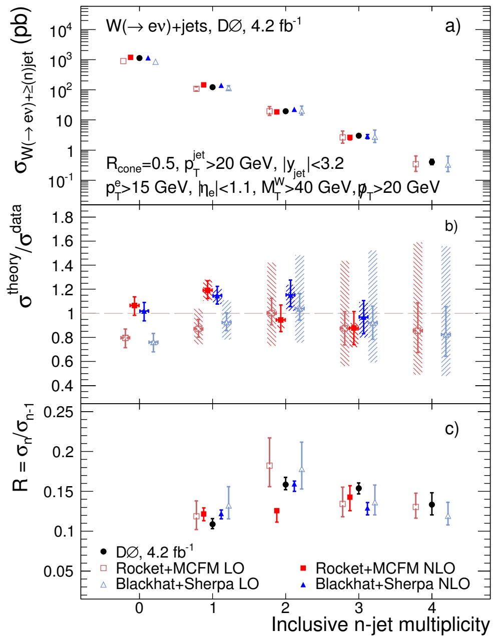

Figure 1: (a) Total inclusive n-jet cross sections $\sigma_n = \sigma(W \to e\nu) + \geq n$ jet as a function of the inclusive jet multiplicity, (b) the ratio of the theory predictions to the measurements, and (c) σ_n/σ_{n-1} ratios for data, BLACKHAT and ROCKET+MCFM. Error bars on data points represent combined statistical and systematic uncertainties on measured cross sections. The uncertainties on the theory points in (a) and (c) and the hashed areas in (b) represent the theoretical uncertainty arising from the choice of renormalization and factorization scale. In (b) the error bars on the points represent the data uncertainties.

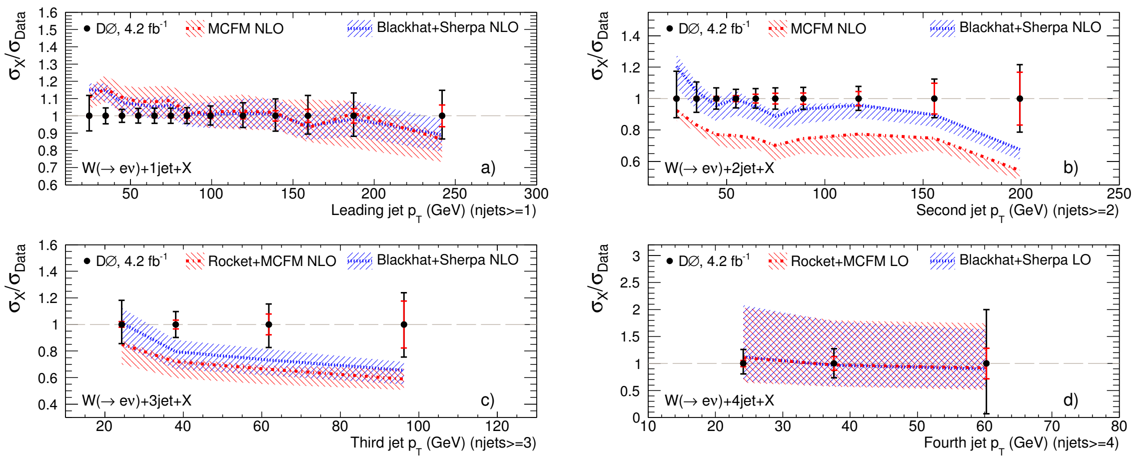

Figure 2: The ratio of PQCD predictions to the measured differential cross sections for the n-th jet versus p_T(jet) in (a) $W+1$ jet events, (b) $W+2$ jets events, (c) $W+3$ jets events, and (d) $W+4$ jets events. The data and theory predictions are normalized by the measured inclusive W boson cross section and the predicted inclusive W boson cross sections, respectively. The inner (red) bars represent the statistical uncertainties of the measurement, while the outer (black) bars represent the statistical and systematic uncertainties added in quadrature. The shaded areas indicate the theoretical uncertainties due to variations of the factorization and renormalization scale. The central scale choice used for each prediction is indicated in the figure.

Both the di-electron and di-muon decay channels are studied. Events are selected as follows: electron (muon) $p_T > 15(10)$ GeV, pseudorapidity $|\eta(e)| \leq 1.1$ or $1.5 < |\eta(e)| < 2.5$ ($|\eta(\mu)| < 2.0$) and $p_T(\text{jet}) \geq 20$ GeV for the leading jet and 15 GeV on any subsequent jets and pseudorapidity $|\eta(\text{jet})| < 2.5$. Events with missing transverse energy ≥ 60 GeV are rejected to suppress the background from $t\bar{t}$ production.

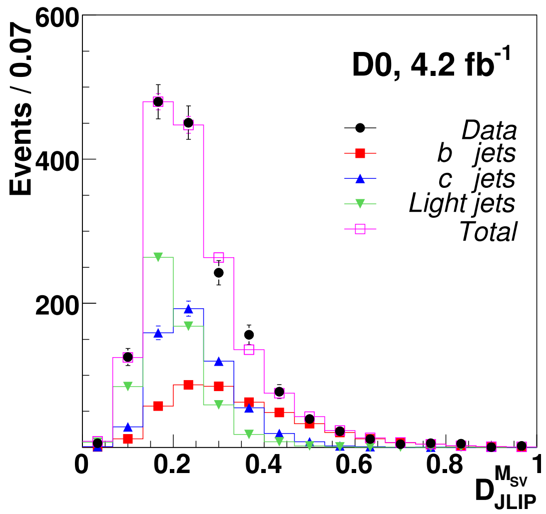

Figure 3: Distribution of the final Neural Network discriminant output for events in the combined lepton data sample, and the fitted light, b and c jet (and total) templates. Uncertainties shown are statistical only.

It is particular challenging to extract the relatively small $Z+b$ signal. Candidate events are separated from light and charm jet candidates by using a Neural Network (NN) based b-tagging algorithm to distinguish the jet flavors. This NN is based on seven input variables, sensitive to properties of the decaying b quark like secondary vertex, lifetime of the b-jet candidate and more. The final discriminant, D_{JLIP} is calculated for each candidate event, and the resulting distribution is shown in Fig. 3. The light jets are determined directly from data by inverting the NN selection requirements which creates a sample enriched with light flavor jets. Heavier c and b jets are taken from MC simulation. An unbinned maximum likelihood fit of these three templates to the data is performed for each of the di-lepton channels in order to extract the flavor fraction. Consistent results are observed between both channels, then the data are combined and a new fit performed. The result of the combined maximum likelihood fit is $\sigma(Z+b\text{jet})/(Z+\text{jet}) = 0.0193 \pm 0.0022(\text{stat}) \pm 0.0015(\text{syst})$ which represents the most precise ratio to date. The systematics are dominated by the template shape (4.2%) and efficiency uncertainties (3.7%). An NLO prediction from the MCFM program for the ratio yields 0.0185 ± 0.0022 (corrected for hadronization and underlying event effects), in reasonable agreement with the data measurement.

2.2 $Z+$jets Angular Correlation

Reference [4] describes the first measurement of angular correlations between the leading jet and the Z/γ in $Z/\gamma^* \to \mu^\pm\mu^\mp +$jet events analyzed from 0.97 fb^{-1}of data collected with the DØ detector. The event selection requires $|\eta(\mu)| \leq 1.7$, $p_T(Z) > 25(45)$ GeV, $p_T \geq 20$ GeV and $|y| < 2.8$. Differential cross-sections are measured as a function of azimuthal angle, absolute rapidity difference, and the absolute value of the average rapidity of the Z and leading jet. The total cross section is normalized to the inclusive Z boson cross-section to reduce uncertainties. These variables provide a unique test of *pQCD* calculations as they are sensitive to effects not probed in e.g. p_T distributions. The measurements are corrected back to particle-level accounting for detector resolution and efficiencies, and compared to NLO *pQCD* predictions (using PYTHIA-derived non-perturbative corrections), as well as a selection of parton shower and PS+matrix element MC generators. Reasonable agreement is observed between NLO and data. Within MC generators studied, SHERPA is found to offer the best description of the shapes of the distributions. Generally, each of the generators ALPGEN, PYTHIA and HERWIG have problems describing both, shape and/or normalization in data depending on the phase space.

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