Jet Production Measurements at DØ

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We report on jet production measurements with the DØ experiment in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV. Measurements of the inclusive jet cross section, of the high-p_T μ-tagged cross section, and of the Z+jets cross section are presented and compared to perturbative QCD leading order and next-to-leading order predictions.

1 Introduction

Jet production processes are described using perturbative QCD. In order to test the models and constrain their parameters, most importantly the parton density functions (PDFs), measurements of jet production in various channels are performed. These measurements are also sensitive to new physics in energy regimes which are not accessible by other processes. In addition, processes with direct jet production are major backgrounds to other Standard Model processes, such as top, W/Z, or Higgs production, and a detailed understanding and accurate prediction of jet production is therefore desirable. We present measurements of jet production which utilize Run IIa datasets recorded by the DØ detector [2].

2 Jet reconstruction and energy corrections

Jets in DØ are reconstructed by combining energy deposits in the calorimeter using the DØ Run II midpoint cone algorithm [3]. The energy of the reconstructed jets needs to be corrected for resolution and energy scale effects in order to bring them to the same level as particle level jets in simulated events. Since the energy scale corrections are a major source of the total uncertainties, they are discussed briefly here. The particle level jet energy is obtained from the calorimeter jet energy by subtracting offset energy and correcting for the calorimeter response and showering: $E_{ptcl} = (E_{cal} - \text{Offset}) / (\text{Response} \times \text{Showering})$. The offset accounts for additional energy in the jet not originating from the hard process (underlying event, pile-up, calorimeter noise). The response corrects for the fraction of energy measured by the calorimeter, which is typically 60% to 80% for raw jet energies between 20 GeV and 300 GeV for a cone size of $\Delta R = 0.7$. Showering corrects for energy leaking inside and outside the jet cone. The total uncertainty on the jet energy scale (JES) corrections is about 2% for central jets with energies between 50 GeV and 150 GeV, but increases rapidly for jet energies outside this range or jets at higher rapidities.

3 Inclusive jet cross section

The measurement of the inclusive jet cross section has been updated with the final luminosity value for this dataset and is based on an integrated luminosity of 0.9 fb^{-1} [4].

A variety of single jet triggers with different prescale sets are used to cover a large transverse momentum range (Fig. 1, left). Events are selected based on run quality, jet quality criteria, and rejection of background (mostly from cosmic muons) by requiring missing $E_T < 0.7p_T^{jet}$ and primary vertex $z < 50$ cm. The analysis is carried out for two rapidity

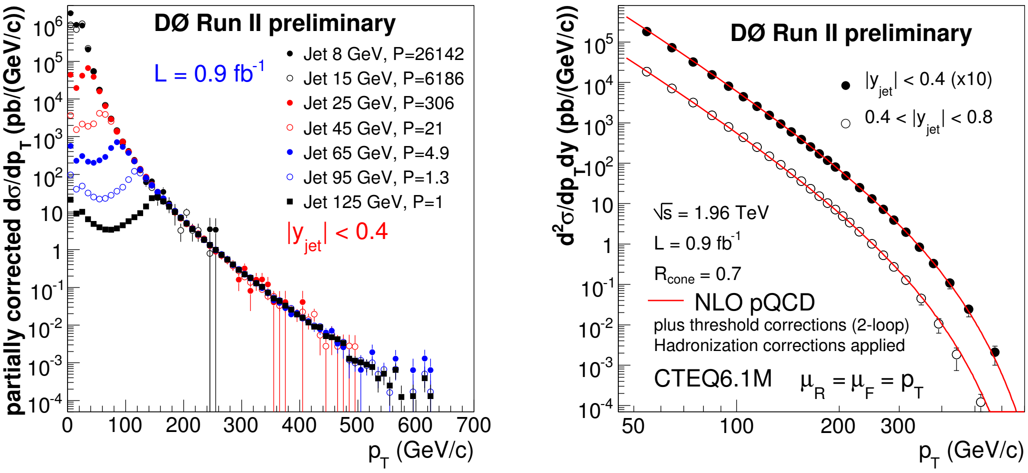

Figure 1: Left: partially corrected inclusive jet cross section for various single jet triggers and rapidity smaller than 0.4. Right: Inclusive jet cross section after resolution corrections.

ranges, $|y_{jet}| < 0.4$ and $0.4 < |y_{jet}| < 0.8$. The data are corrected for resolution and migration effects by unfolding the partially corrected cross section. The unfolding function is a convolution of an ansatz function and the jet p_T resolution measured from the p_T balance in dijet data events. The procedure is cross checked by smearing jets in simulated events with the measured resolution function, and is found to be in good agreement.

The unfolded inclusive jet cross section is shown in Fig. 1, right, and compared to a next-to-leading order prediction [5]. The prediction agrees with the data over the whole p_T range which spans eight orders of magnitude in the cross section. Figure 2, left, shows the ratio between data and prediction of the inclusive jet cross section for $|y_{jet}| < 0.4$. The prediction uses renormalization and fragmentation scales set to p_T^{jet}, CTEQ6.1M PDFs, and 2-loop threshold corrections. The shaded bands indicate the experimental uncertainties, the dashed line shows the uncertainty on the predication from the PDFs, and the dash-dotted line the prediction without 2-loop threshold corrections. The right-hand plot in Fig. 2 compares data to predictions with three different PDF sets, where the ratio is normalized to CTEQ6.1M PDFs. This set also gives the best description of the data. At high p_T the experimental uncertainties are dominated by the statistical error on the jet energy scale corrections. This error is expected to be reduced when JES corrections based on the full Run IIa dataset become available.

4 High-p_T μ-tagged cross section

Deviations in the jet production mechanism from the Standard Model prediction are more likely to show up in the third quark generation, where the quarks have non-negligible masses. A measurement of $X \to b\bar{b}$ could therefore shed light on new physics, and so a measurement of the inclusive heavy flavor cross section has been performed on 300 pb^{-1} of data. The data sample is enriched in jets from heavy flavor quarks by requiring a soft muon inside the jet

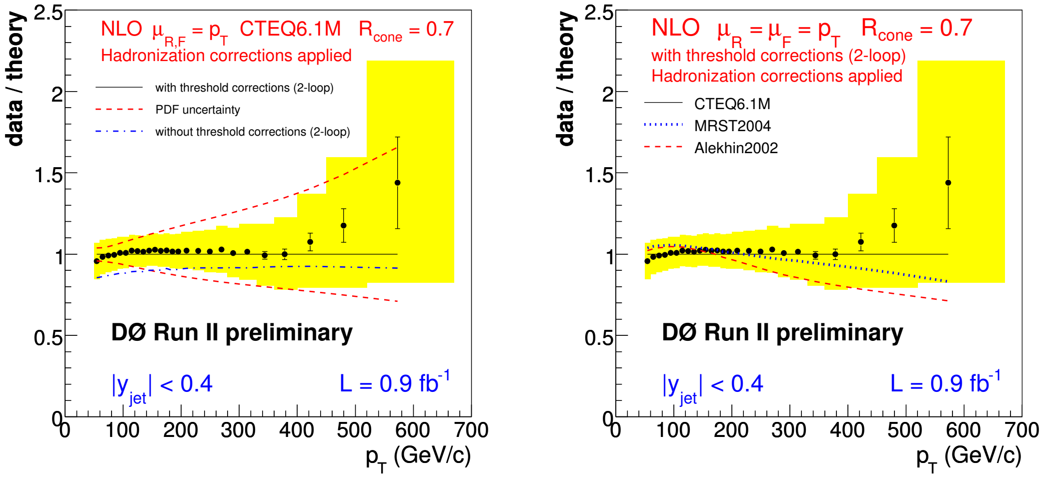

Figure 2: Left: Measured inclusive cross section, relative to a NLO prediction with CTEQ6.1M PDFs. Right: Comparison of the data to predictions from different PDFs.

cone. The μ-tag does not separate jets from b and c quarks, so the measured cross section is that of inclusive heavy flavor jets. Events are selected if at least one of the two leading jets is μ-tagged and lies within $|y_{jet}| < 0.5$. Depending on the specific trigger, a jet p_T threshold is chosen such that the trigger efficiency is at least 90%. The total event selection efficiency, including object identification efficiencies, is $31 \pm 4\%$, where the largest inefficiency stems from the muon reconstruction.

Jets matched to a muon usually originate from heavy flavor hadrons with a direct or cascade semi-leptonic decay. Since the energy of the involved neutrino cannot be measured and the muon deposits only a small fraction of its energy in the calorimeter, special energy corrections are applied to μ-tagged jets, which are derived mainly from $Z \to b\bar{b}$ Monte Carlo events. A cross check, based on the p_T imbalance of dijet data events, where one jet is μ-tagged and the other jet is not μ-tagged, shows that an additional correction is needed for μ-tagged jets in dijet events. The jet energy resolution for the unsmearing is also measured specifically for μ-tagged jets.

To calculate the μ-tagged cross section from heavy flavor hadrons, the fraction of μ-tagged jets from light flavors has to be subtracted. The heavy flavor fraction is estimated from simulated Pythia events and a full detector simulation, see left-hand plot in Fig. 3.

The right-hand plot in Fig. 3 shows the measured cross section relative to the theory prediction from Pythia with particle-level jets. Since Pythia is a leading-order Monte Carlo, the size of higher-order corrections is estimated by simply comparing the next-to-leading order cross section calculations from NLOJET++ [9] to the leading-order Pythia prediction. The data is found to lie in between these two predictions.

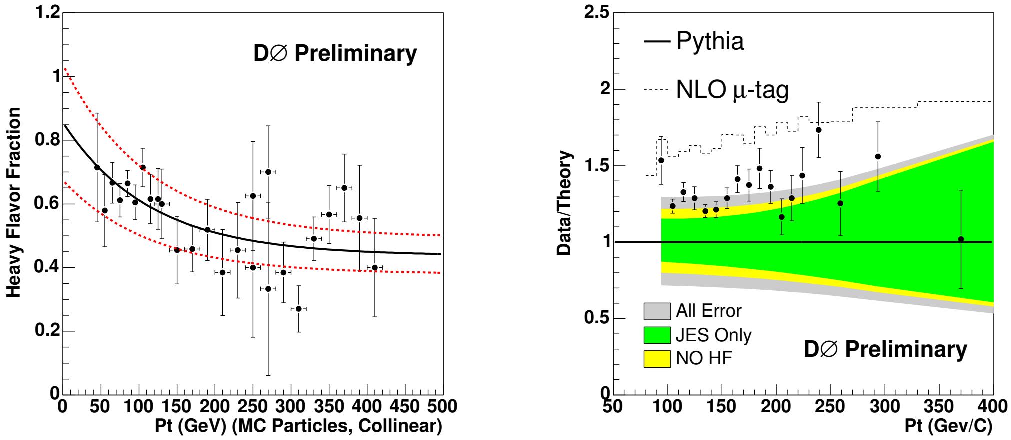

Figure 3: Left: Heavy flavor fraction in the μ-tagged sample estimated from Monte Carlo events. The dashed line indicates 20% systematic uncertainties. Right: Comparison to theory predictions. The error bands indicate the uncertainties on the measurement.

5 Z+jets cross section

The measurement of the production rates of jets accompanied by a W or Z boson which decays into leptons gives a good handle to test perturbative QCD calculations, especially the modeling of extra jet radiation. W/Z+jets events are also an important background to top and Higgs signals, and need to be understood well. It is therefore important to compare the available Monte Carlo simulation to data distributions.

The presented analysis measures the cross section of Z+jets events with Z$\rightarrow e^+e^-$ in 400 pb^{-1} of data. Events are selected if they pass certain quality criteria and have at least two reconstructed electrons with $E_T > 25$ GeV in the central region $|\eta_{det}| < 1.1$ of the detector. The invariant mass of the electron pair must be consistent with the Z boson mass, 75 GeV $< M_{ee} <$ 105 GeV. Jets are reconstructed with a cone size $R_{cone} = 0.5$. The measurements are corrected for reconstruction and acceptance efficiencies and jet energy resolution effects.

The fractional cross sections for Z+jets events in each jet multiplicity bin, compared to the inclusive Z+jets cross section, is shown in Fig. 4, left, together with predictions from Pythia [6], a leading-order matrix element calculation (Madgraph) [7] with parton showering and hadronization from Pythia (ME-PS), and from MCFM [8] for the one and two-jet bin. The matrix-element based predictions agree well with the data, whereas the Pythia prediction lacks events in the higher jet multiplicity bins as expected from a leading-order calculation. The right-hand plot in Fig. 4 shows the p_T spectra of the three highest p_T jets in data and the Madgraph predication with parton showers from Pythia. Good agreement is observed over many orders of magnitude in the cross section. The measurement is limited by systematic uncertainties with the jet energy scale as a dominant source.

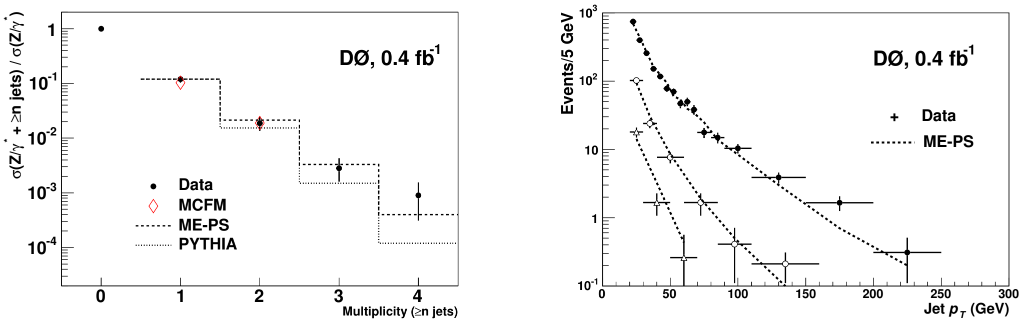

Figure 4: Left: Fractional cross section as a function of the number of reconstructed jets. The errors on the data include both statistical and systematic uncertainties. Right: spectra of the highest, second highest, and third highest p_T jet in data and the ME-PS prediction.

6 Summary

Three examples of jet production measurements utilizing data recorded with the DØ detector have been presented: the inclusive jet cross section, the high-p_T μ-tagged cross section, and the Z+jets cross section. Generally, the measurements agree well with next-to-leading order and matrix-element based predictions and help constraining theoretical models, for example for the quark and gluon PDFs. The dominant uncertainties from the jet energy scale can be improved significantly when JES corrections based on a larger data sample are available.

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