Fermi National Accelerator Laboratory

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Measurement of $R_{10}(\sigma(W+\geq 1\ Jet)/\sigma(W))$ at CDF

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We present a measurement of the (W + $\geq$1 Jet)/(W Inclusive) cross section ratio, R_{10}, in $W \rightarrow e\nu$ events for jet E_T thresholds ranging from 15 to 95 GeV. Using roughly 100 pb^{-1} of data from the $\sqrt{s} = 1.8$ TeV $p\bar{p}$ collisions at the Fermilab Tevatron Collider, we compare the measured values of R_{10} to LO and NLO QCD predictions. Comparisons are made for both 0.4 and 0.7 jet cone clustering. Good agreement between data and theory is observed over a large range of jet E_T thresholds for both cone sizes.

1 Introduction

Measurement of the ratio of the cross section for W + $\geq$1 jet to the inclusive W cross section tests QCD predictions for jet production associated with a W event. Many uncertainties (experimental and theoretical) cancel in the ratio and thus precise comparisons are possible. Previous studies [1] were performed with a jet cone radius R = 0.4. Good agreement between data and the NLO predictions was observed for jet E_T above about 30 GeV. In this paper, preliminary results for an identical analysis using a cone size of R=0.7 is presented. Differences between the agreement with theory for two different cone sizes indicate the ability of the NLO theory to model the jet shapes as well as the overall rate of jet production in W events. Interest in the large cone size result is also motivated by the large discrepancies (a factor of 1.5-2) between data and theory reported by the D0 collaboration [2] where a cone size of 0.7 was used. Similar measurements by the UA1 and UA2 collaborations [3,4] found good agreement with theoretical predictions with significantly smaller data samples and a center of mass energy of 630 GeV.

2 Event Selection

The event selection for the cone size 0.7 analysis is essentially identical to the cone size 0.4 analysis [1]. The W events are identified by requiring a high E_T central electron ($E_T >$ 20 GeV, and $|\eta| \leq 1.1$) along with a large missing E_T ($>$ 30 GeV). Jets were identified with a cone algorithm where the radius of the cone was either R = 0.4 or 0.7. Jets were required to be within $|\eta| \leq 2.4$ and the minimum jet E_T cut was varied from 15 - 95 GeV. No out-of-cone corrections were applied to the jet energies as this effect should be modeled by the NLO predictions. Z events were removed with a cut on M_{ee} of 76 GeV-106 GeV. Events with jets near the electron were rejected by requiring $\Delta R_{ej} > 1.3\ R_{avg}$, where $R_{avg} =< R^{jet} + R^e >$ and the electron cone $R^e = 0.4$. For jet cones of 0.4 and 0.7, ΔR_{ej} >0.52 and 0.715 respectively. The total number of W candidates after these cuts is 51437. The fraction of events with one jet of E_T >15 GeV is 15% for a cone size of 0.4 and 20% for cone size 0.7. With a 95 GeV cut on the jet E_T these fractions drop to 0.4% and 0.5% respectively.

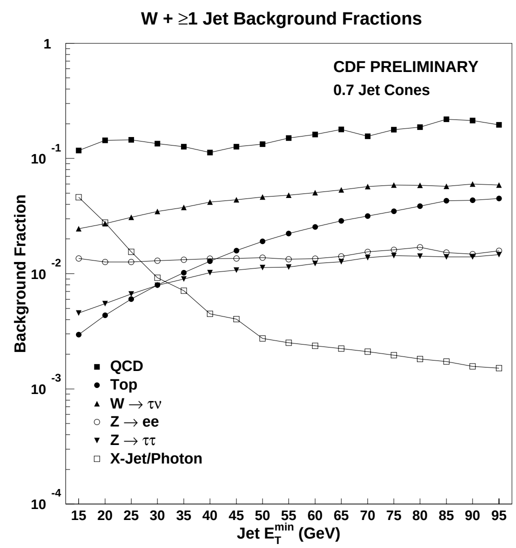

Figure 1: Background contributions to the $W + \geq 1$ jet cross section as a function of jet E_T cut.

3 Corrections to data

3.1 Backgrounds

Corrections to R_{10} for backgrounds are calculated for each E_{Tmin} for each cone size. The background fractions in the $W+ \geq 1$ jet sample for cone 0.4 and 0.7 are very similar. The contribution from the various sources for the cone size 0.7 are shown in Figure 1. The dominant background comes from QCD multi-jet events where one of the jets fakes the electron from the W decay and a large missing E_T results from jet energy mismeasurement due to shower fluctuations or uninstrumented regions of the calorimeter. The fraction of events from this source is

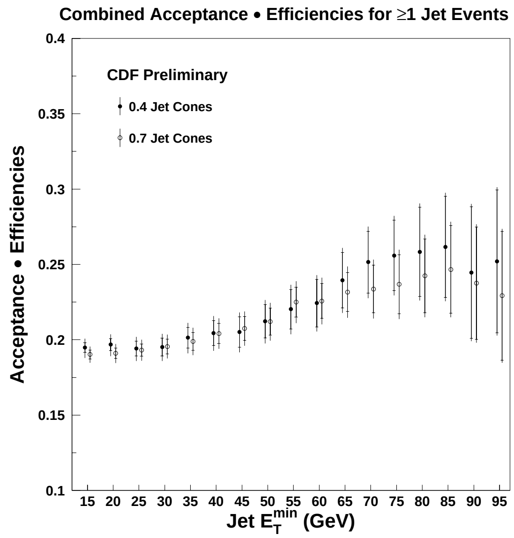

Figure 2: Acceptance and efficiency for the $W+\geq 1$ Jet cross section as a function of Jet E_T cut for cone sizes 0.4 and 0.7.

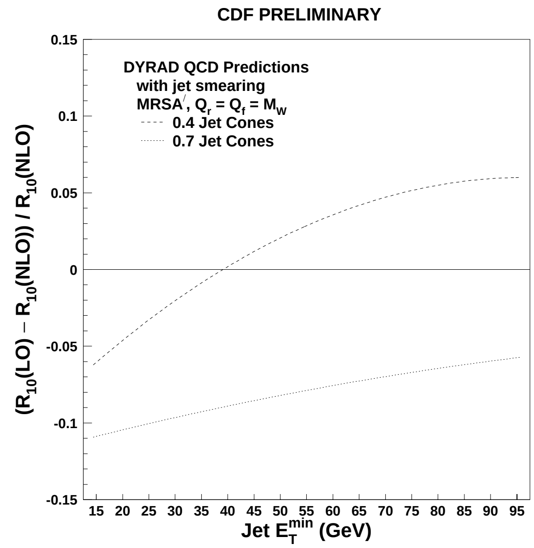

Figure 3: Comparison of LO and NLO predictions for different cone sizes.

estimated by removing the electron isolation requirement and the missing E_T cut in the W selection. Other sources of background include processes that produce an electron and missing E_T. The VECBOS Monte Carlo program [5] and the CDF detector simulation are used to estimate the contributions from $W \to \tau\nu$ (with $\tau \to e\nu\nu$), $Z \to \tau^+\tau^-$, and $Z \to e^+e^-$ (where one electron is not identified). The contribution of standard model top (where $t \to Wb$ and $W \to e\nu$) is also removed as a background. Multiple $p\bar{p}$ interactions in the same event can contribute extra jets, as can $W\gamma$ events where the photon is reconstructed as a jet. The combined effect from these two sources is largest at low E_T, where it is easy to create a jet, and quite small above about 30 GeV. In both the cone 0.4 and the 0.7 sample, the total background fraction varies from 21% at $E_{Tmin} = 15$ GeV to $\sim 35\%$ at $E_{Tmin} = 95$ GeV. The background fraction in the inclusive W sample is 6%.

The data are also corrected for W acceptance and detection efficiency as a function of E_{Tmin}. The corrections are shown in Fig. 2 for the two cone sizes. The acceptance for $W \to e\nu$ events corrects for the fiducial and kinematic requirements on the electron and missing E_T and is determined using the VECBOS Monte Carlo and CDF detector simulation. The efficiency for detecting $W \to e\nu$ events includes effects from the trigger, electron ID and the electron-jet overlap. The electron ID and electron-jet overlap efficiencies are determined from $Z \to e^+e^-$ events. The overall efficiency for both cone sizes for $W+\geq 1$ jet varies from $\sim$ 19-25% as the E_T of the jet cut is varied from 15 to 95 GeV. The efficiency for the inclusive W sample is 20%.

4 Comparisons to Theory

Theoretical predictions are generated using the DYRAD [6] Monte Carlo program. DYRAD calculates the NLO matrix elements for inclusive W (order α_s) and for $W+\geq 1$ jet (order α_s^2). Individual samples of $W \to e\nu$ events are generated with $\geq$1 or $\geq$0 jets. A minimum parton E_T cut of 7 GeV was used and no cuts on the W boson or leptons were applied. The prediction for R_{10} is found by dividing the cross section for $W+\geq 1$ jet by the cross section for inclusive W production. The cross sections depend on the choices for renormalization (Q_r) and factorization (Q_f) scales. For these comparisons we have set the renormalization scale equal to the factorization scale. At NLO, the $W+\geq 1$ jet cross section calculations include diagrams with up to two partons in the final state. To simulate the jet clustering and merging, partons within $1.3R^{jet}$ are combined (0.91 for cone 0.7 and 0.52 for cone 0.4) to form one "jet". Thus, at NLO, the resulting cross section for $W+\geq 1$ jet events is a function of the jet cone size. The generated jet energies are then smeared in η, E_T and ϕ to model detector resolution effects [7]. Finally, the jet E_T and $|\eta| <2.4$ cuts are applied to the smeared jets, as in the analysis of the data. Figure 3 shows a comparison of NLO theory with different cone sizes to the LO prediction. The NLO predictions with cone 0.7 are roughly 11% larger than LO at low E_T and 7% larger at high E_T. For a cone size of 0.4, The NLO predictions start out about 6% larger than LO

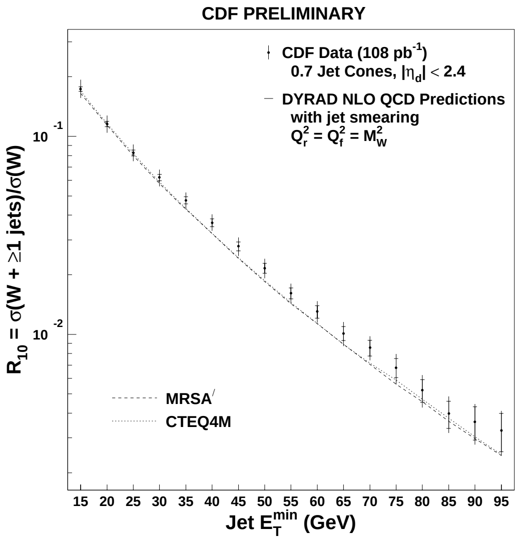

Figure 4: NLO predictions to data for cone size R=0.7. The inner error bars are statistical. The outer error bars include systematic uncertainties on R_{10} from jet counting, backgrounds, acceptances and efficiencies.

at low E_T and decrease to 6% smaller than LO at high E_T.

A comparison of data to QCD predictions with a cone size of R=0.7 is shown in Figure 4. Good agreement is observed for both the MRSA'[8] and CTEQ4M[9] parton distribution functions (PDFs).

Figure 5 shows the percentage difference between data and theory for the two cone sizes. Also plotted is the percentage difference between the theoretical predictions when different renormalization and factorization scales are used. The effect of the different Q^2 scales at NLO is $\leq$5% for cone size 0.4 and slightly larger at high E_T for cone size 0.7.

Naively, one would assume that the ratio of the W cross section with jets to the inclusive W cross section would be sensitive to the value of α_s. Sets of parton distribution functions have been generated for a range of values of α_s corresponding roughly to the range allowed by the world data. Figure 6 shows a comparison of data to QCD predictions with different values of α_s for a cone size of R=0.7 for PDF sets from MRSA[10] and CTEQ. The comparisons are shown for jet $E_T > 30$ GeV and for jet $E_T > 60$ GeV. The measurement of R_{10} is in good agreement with the all values of α_s and the dependence of R_{10} on the value of α_s is reduced at high jet E_T.

To study the dependence of R_{10} on cone size we take the ratio of the R_{10} spectra for the two cone sizes. Figure 7 shows the ratio of R_{10} for cone size 0.7 to cone size 0.4 compared to the NLO theoretical predictions. The R_{10} measured in the data increases by $\sim 30\%$ when the

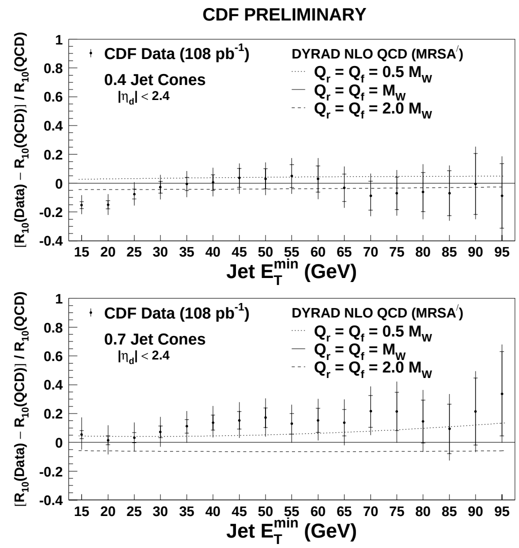

Figure 5: (Data - theory)/theory is plotted for different Q^2 scales and cone sizes as a function of the minimum jet E_T.

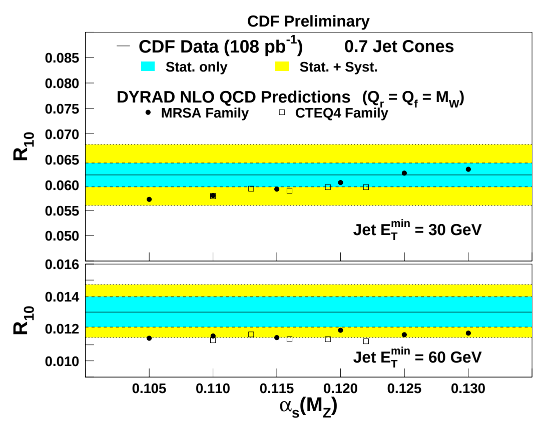

Figure 6: Dependence of the theoretical predictions on the value of α_s used in the calculations compared to the results from the data for jet cuts of 30 and 60 GeV. The inner band represents the statistical uncertainty. The outer band represents the combination of systematic and statistical uncertainties.

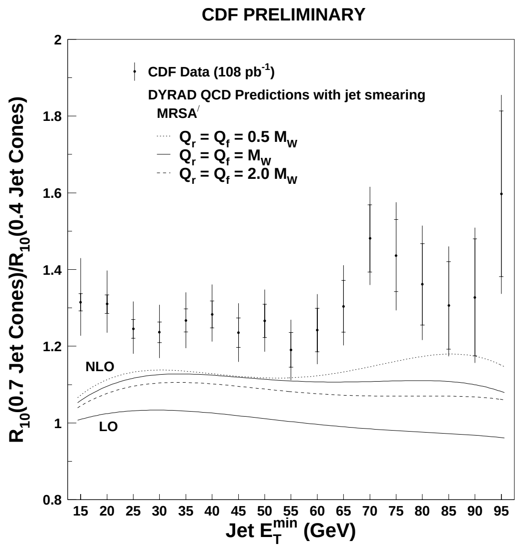

Figure 7: R_{10} for cone size 0.7 divided by R_{10}, for cone size 0.4

larger cone is used while the theory predictions increase by $\sim$ 10%. This suggests that the theory jet shape is narrower than the jet shape found in the data.

5 Conclusions

CDF has measured the ratio of cross sections for $W+ \geq 1$ jet to inclusive W production for two cone sizes as a function of the jet E_T cut. For a cone size of 0.4 the data and theory are in good agreement above $\sim$ 30 GeV. For a cone size of 0.7 the data and theory agree well at low E_T, while the data exceeds the predictions by $\sim$ 15% ($\sim 1\sigma$) for $E_T^{min} > 35$ GeV. NLO theory predicts a smaller increase when going to a larger cone than is observed in the data, roughly 10% predicted and 30% observed. The quantity R_{10} is not very sensitive to the value of α_s. Calculations of R_{10} for the available values of α_s are all in good agreement with the CDF data.

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