Fermi National Accelerator Laboratory

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A Measurement of the Ratio of W+1 Jet to W+0 Jets Cross Sections and Comparisons to QCD

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A Measurement of the Ratio of $W+1$ Jet to $W+0$ Jets Cross Sections and Comparisons to QCD

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Abstract

A preliminary measurement of the ratio, $\mathcal{R}^{10}$, of the production cross sections for $W+1$ Jet and $W+0$ Jets processes at $\sqrt{s}=1800$ GeV by the DØ Collaboration is presented. A comparison of this ratio is made to next-to-leading order calculations and the implications of these comparisons, especially for the extraction of a value for the strong coupling constant $\alpha_S(M_W^2)$, are discussed.

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I. INTRODUCTION

The UA1 and UA2 experiments [1,2] used events with a W boson and jets to measure the ratio, $\mathcal{R}^{10}$, of the production cross sections for $W+1$ Jet events to $W+0$ Jets events and then used theoretical calculations to extract a value for the strong coupling constant at the mass of the W, $\alpha_S(M_W^2)$. The DØ collaboration has also published [3] a measurement of the ratio of production cross sections using the data from the 1992-1993 run of the Fermilab Tevatron Collider. The preliminary result presented here is from the 1994–1995 run and thus uses a data set more than six times as large as that used for the previous DØ result.

In principle the measurement of α_S using $W+$ Jets events is elegantly simple. Many potential sources of systematic errors cancel in the ratio. The theoretical ratio has been calculated to next-to leading order and depends on the parton distribution functions (pdf's) of the proton and the value of α_S at the mass of the W, $\alpha_S(M_W^2)$. The theoretical predictions can then be compared to the experimentally measured ratio and a value for α_S at $Q^2 = M_W^2$ extracted. The UA1 and UA2 experiments did just this using tree level calculations and K-factor corrections to partially account for next-to-leading order (NLO) contributions.

However, the published DØ [3] result shows that the theoretical predictions for $\mathcal{R}^{10}$ calculated using the NLO DYRAD Monte Carlo [4] at a center of mass energy, $\sqrt{s}$, of 1800 GeV are relatively insensitive to α_S because the theoretical predictions over a wide range of α_S yield a nearly constant value of $\mathcal{R}^{10}$. This could be due to changes in the gluon distribution canceling changes in the matrix element as α_S is varied in the calculations. These changes in the gluon distribution are possible since the gluon distribution of the proton is not well constrained by the available data.

The new DØ result presented here has the advantage of higher statistics, allowing for tighter cuts which reduce the amount of background in the sample. The higher statistics sample also allows us to eliminate data from fiducial regions of the detector where backgrounds are highest. All of this contributes to smaller errors on the experimental ratio.

II. DATA SELECTION AND COMPARISONS TO QCD

The DØ detector and the details of the DØ triggering system have been described elsewhere [5]. The important systems in the detector for this analysis are the uranium–liquid argon calorimeter for energy measurements and the central drift chambers for tracking. The relevant details of the triggering for this analysis are listed below.

- Calorimeter electromagnetic shower transverse energy requirement at the hardware level.

- Calorimeter electromagnetic shower shape and transverse energy requirements at the online software level.

- A matching track in the central tracking to the electromagnetic shower requirement at the online software level.

- A requirement for the presence of missing transverse energy, $\not\!\!E_T$, at the online software level.

- Background triggers have looser electromagnetic shower requirements at the hardware and the software levels and no $\not\!\!E_T$ requirement.

The data sample used for this study is defined offline by selecting W boson events in which the W has decayed to an electron and an electron neutrino, $W \rightarrow e\nu$, without a cut on the jet multiplicity. The cuts on the electron are:

- transverse energy, E_T, greater than 25 GeV,

- the electron candidate must be well separated in pseudorapidity η and azimuthal angle ϕ from other objects in the calorimeter,

- selection based on the quality of the match of the electromagnetic shower shape in the calorimeter to a known electron shower,

- pseudorapidity η of the electromagnetic shower is restricted to the central region, $|\eta| < 1.1$,

- electromagnetic fraction of the calorimeter shower greater than 95%,

- selection based on the quality of the match between the calorimeter shower position and the position of the associated track,

- events with more than one electron passing the above cuts are removed to eliminate Z boson events where the Z decayed to an electron-positron pair.

The $\not\!\!E_T$ in the event is also required to be greater than 25 GeV. Jets in these events are identified using a fixed cone algorithm with a radius of 0.7 in η–ϕ space. Jet quality cuts are applied to remove events with fake jets due to detector effects or beam conditions. The analysis has been performed using several different minimum E_T, E_T^{min}, requirements used to define the jets. The standard value is chosen to be 25 GeV.

III. BACKGROUNDS

The dominant background in $W+$ Jets events is from multi-jet events produced by strong interaction processes in which one jet fluctuates highly electromagnetically and another jet is sufficiently mismeasured that substantial $\not\!\!E_T$ is seen in the event. The estimate of the amount of background from this source is made using data and is explained below.

Two samples are extracted from data from the background triggers (no $\not\!\!E_T$ cut). One set contains signal and background events which are selected by requiring a good electron candidate, one which passes the electron cuts listed previously, in the event. The second sample contains background only and is selected by making cuts which preferentially select non-electrons. The assumption is that events with an electron candidate but only a small amount of $\not\!\!E_T$ are actually multi-jet events (background) in which a jet faked an electron in the calorimeter since a major source of single high p_T electrons is W boson production.

The $\not\!\!E_T$ distribution for the sample containing only background events is then area normalized to the $\not\!\!E_T$ distribution for the signal plus background sample in the low $\not\!\!E_T$ region, $\not\!\!E_T <$ 15 GeV, and the normalization factor, N, is extracted. (Figure 1)

Two similar samples are extracted from the $W \rightarrow e\nu$ signal trigger (which employs a $\not\!\!E_T$ cut). The normalization factor, N, is then applied to the $\not\!\!E_T$ distribution for the background only sample from the signal trigger. The background fraction is then the number of events from the background sample in the signal region ($\not\!\!E_T >$25 GeV) multiplied by N and divided by the number of events from the signal plus background sample in the signal region. This results in a background fraction of 1.6% for $W + 0$ Jets and 6.8% for $W + 1$ Jet for an E_T^{min} cut of 25 GeV.

Other backgrounds include Drell–Yan, $\gamma^* \rightarrow e^+e^-$, events and Z boson production events

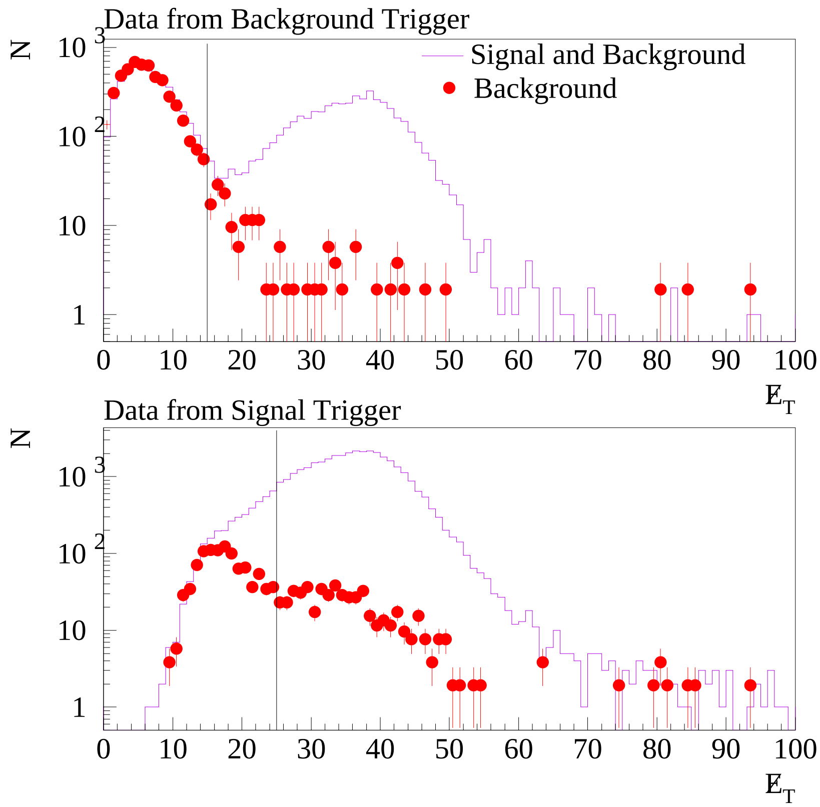

FIG. 1. The top figure shows the $\not{E}_T$ distributions for the two samples from the background trigger. The points have been area normalized to the histogram for $\not{E}_T$ <15 GeV. The bottom figure shows the $\not{E}_T$ distributions for similar samples from the signal trigger. The normalization factor N from the top plot has been applied to the background data (the •).

in which the Z decays to an electron-positron pair, $Z \rightarrow e^+e^-$, when an electron is lost, and $Z \rightarrow \tau\tau$ events in which one τ decays to an electron and the other decays to hadrons. The fraction of contamination from these types of events was estimated using the ISAJET Monte Carlo [6] and is about 2% in the case of $W + 1$ Jet events and less than one percent for $W + 0$ Jets events.

IV. EXPERIMENTAL RESULTS AND COMPARISONS TO QCD

For 83 pb^{-1} of data from the 1994-1995 run of the DØ detector at the Tevatron Collider we obtain 36,891 $W \rightarrow e\nu$ candidates with electrons restricted to the central part of the DØ calorimeter ($|\eta|$ <1.1). For a cut on E_T^{min} of 25 GeV there are 33,511 $W + 0$ Jets candidates and 2,841 $W + 1$ Jet candidates. After subtracting the background contributions from multi-jet events and from other electroweak processes these numbers become 32,835 for $W + 0$ Jets and 2,599 for $W + 1$ Jet. This results in a ratio of

$$\mathcal{R}^{10}_{exp}(preliminary) = 0.079 \pm 0.002^{stat} \pm 0.005^{sys}.$$

The dominant systematic error is due to the uncertainty in the jet energy scale.

The difference between the central values for this result and the previous DØ result is due to the restriction that the electron must be in the central calorimeter, $|\eta| < 1.1$. The smaller errors for the new result are due to larger statisics.

A comparison of this result with theoretical calculations (Figure 2) using the DYRAD [4] Monte Carlo and the CTEQ3 [7] family of parton distribution functions, in which the distributions were refit for several fixed values of Λ_{QCD}, shows that not only is the prediction two to three standard deviations below the experimental result, but the calculations also exhibit little dependence on α_S making an extraction of α_S by this method impossible. The solid line is the experimental result. The dotted lines indicate the statistical errors only while the shaded region indicates the statistical and systematic errors added in quadrature.

Another way to look at this result is to vary the minimum E_T used to define a jet and compare the experimental trend to that of the theoretical predictions (see Figure 3). The theoretical predictions describe the shape of the E_T^{min} dependence for the different parton distribution functions, however all are consistently below the data. For CTEQ3 there are three different curves plotted for different values of Λ_{QCD}. One is the preferred fit, CTEQ3M ($\Lambda_{QCD} = 0.158$), while the other two are for the extremes in Λ_{QCD} ($\Lambda_{QCD} = 0.100$ and 0.340) for this pdf family. It is evident that while the general shapes of the experimental result and the theoretical predictions are similar, the normalization of the calculations is well below the experimental result and that varying Λ_{QCD} within the limits allowed by the global pdf fits does not bring the predictions into agreement with the experimental result.

It should be noted that when the UA2 experiment published their result on a similar

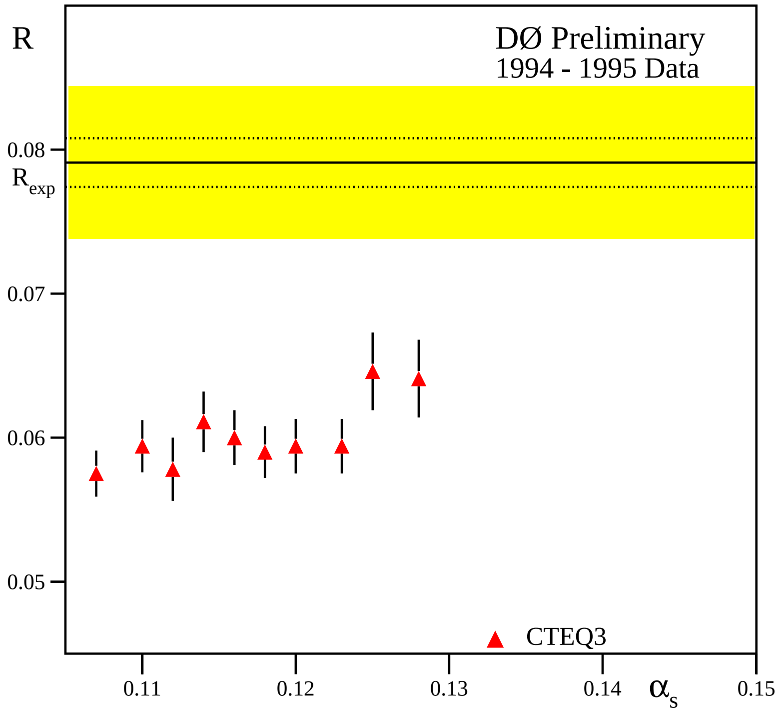

FIG. 2. The ratio, $\mathcal{R}^{10}$, for $E_T^{min} = 25$ GeV. The experimental result is the solid line. Dotted lines indicate the statistical errors and the shaded region represents statistical and systematic errors added in quadrature. The points are DYRAD calculations using the CTEQ3 pdf family.

analysis they commented on the effect of ignoring the α_S dependence in the pdf's and only varying α_S in the matrix element. DØ also performed this study and saw a similar result. If α_S is only varied in the matrix element the dependence of $\mathcal{R}^{10}$ on α_S increases. One difference between UA1/UA2 and the DØ theoretical results is that DØ observes less of a dependence on α_S than UA1/UA2 in the theoretical calculations when α_S is varied in the pdf's as well. One major difference between UA1/UA2 and DØ is the center of mass energy. UA1/UA2 ran at $\sqrt{s} = 630$ GeV while the Tevatron Collider data were taken at $\sqrt{s} = 1800$ GeV. This affects the average momentum fractions of the initial state partons that are probed in the production of a W. This in turn affects the relative fraction of quark-quark and quark-gluon initiated $W + 1$ Jet events in the sample.

Because UA1/UA2 ran at a lower $\sqrt{s}$, the average momentum fraction of the initial state

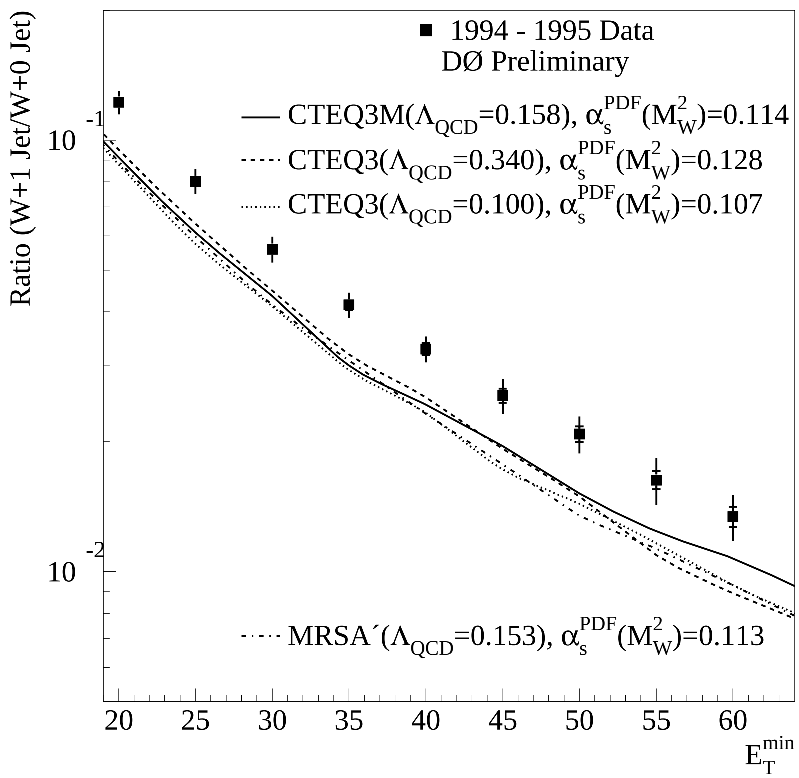

FIG. 3. The ratio, $\mathcal{R}^{10}$, decreases as the minimum jet E_T, E_T^{min}, is increased. The inner error bars are the statistical errors. The outer error bars are statistical and systematic added in quadrature. The solid curve is for the preferred CTEQ3M parton distribution functions and the other CTEQ3 curves span the extremes in α_S. A calculation using MRSA' is also plotted.

partons was larger than the initial state partons in W production at DØ. The average momentum fraction for W production at UA1/UA2 was approximately 0.14 while the average momentum fraction for W production at DØ is about 0.04. This difference results in more of the DØ $W+1$ Jet events being produced from a quark-gluon initial state at 1800 GeV than at 630 GeV. [8] Theoretical predictions for $\mathcal{R}^{10}$ at DØ are therefore more sensitive to the gluon distribution in the proton.

The gluon distribution is not well constrained by current experiments. When the CTEQ3 pdf's are plotted for the different partons in the proton it can be seen that the gluon distribution varies a significantly as Λ_{QCD} is changed in the fits (Figure 4). This variation contributes to the flattening of the theoretical predictions for $\mathcal{R}^{10}$ *vs.* α_S by compensating for the changes in the matrix element as α_S increases.

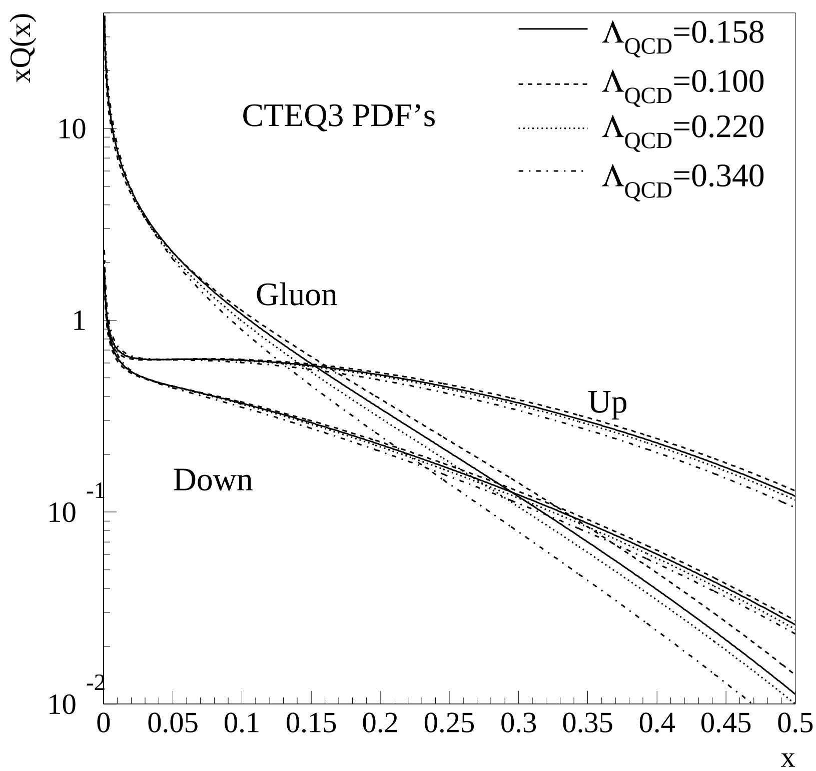

FIG. 4. Parton distributions for the CTEQ3 family are plotted versus the momentum fraction for the parton. The solid line is for CTEQ3M while the other curves span the range for Λ_{QCD} (or α_S) for the CTEQ family.

V. CONCLUSIONS

In conclusion DØ has made a preliminary measurement of the ratio, $\mathcal{R}^{10}$, of production cross sections for $W+1$ Jet to $W+0$ Jets processes with the data from the 1994-1995 run of the Fermilab Tevatron Collider. Comparisons to NLO QCD calculations show that the theoretical predictions are consistently lower than the data for different values of α_S given the currently available parton distribution functions. Also, the theoretical calculations underestimate the rate of jet production in association with W bosons as a function of the minimum jet E_T. It appears that incorporating the DØ and the UA1/UA2 data in global

QCD fits could lead to significant modifications of the conventional understanding of the gluon distribution in the proton.

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