PROCEEDINGS OF SCIENCE

Measurement of W+charm production cross section at CDF

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A measurement of the production cross section of a W boson and a single charm quark, σ_{Wc}, using soft electron tagging is reported. We trigger on high P_T leptons (electrons and muons) and reconstruct 'lepton+jets' events offline. Approximately 4.3 fb^{-1} of data is analyzed. We use soft electron tagging to tag heavy flavor jets. The W+c signal is produced mainly by strange $quark - gluon$ fusion, $sg \rightarrow W^- c$ and $\bar{s}g \rightarrow W^+ \bar{c}$. The signal is evinced through an excess of events in which the W lepton and the soft electron, SLT$_e$, charges are opposite in sign.

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1. Introduction

Associated W+ charm production proceeds, at lowest order, through sg and $\bar{s}g$ fusion: $sg \rightarrow W^{-}c$ and $\bar{s}g \rightarrow W^{+}\bar{c}$. As can be seen in Figures 1, the charge of the lepton from the semileptonic decay of the charm quark and the charge of the lepton from the W boson decay are opposite in sign. We exploit this signature to distinguish Wc events from the large background of other $W+$ jet (light and heavy flavor) events.

At the Tevatron, the $W+c$ signal is approximately 5% of the inclusive W+1 jet cross section for jets with a transverse momentum greater than 10 GeV [1]. The $W+c$ signal is produced mainly by strange quark and gluon fusion. The alternative process where the s quark is replaced by a d quark is suppressed by the CKM quark mixing matrix element V_{cd}. Given the larger d quark parton distribution function, the $dg \rightarrow Wc$ cross section is about 10% of the $sg \rightarrow Wc$ rate. The sum of the dg and sg contribution is considered as our signal.

Wc production is a background process for several important physics signatures such as single top production and associated W + Higgs production and is a significant component in the $t\bar{t}$ control region. Our motivation to perform this analysis is driven by the need to identify Wc events among $W+$ heavy flavor events and to improve the understanding of backgrounds of the aforementioned processes as well as the understanding of the charm tagging performance. A CDF measurement of the Wc production cross section with soft muons tagging using $\sim 1.8\ fb^{-1}$ is reported in [2].

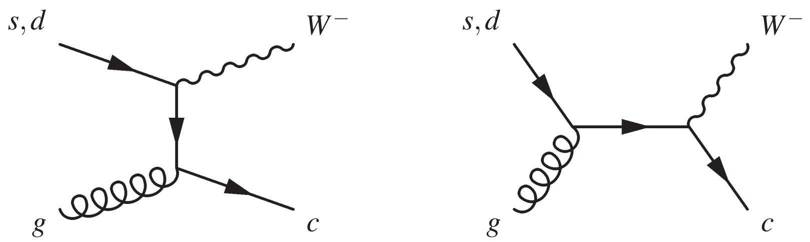

Figure 1: The leading order Feynman diagrams for W+charm production

2. Measurement Strategy

We select events in which the W boson decays leptonically, looking for a signature of one isolated lepton (e or μ), missing transverse energy, and one reconstructed jet. A cut on the transverse mass of the W boson at 20 GeV has been applied to further reduce the contribution of multijet QCD background events.

No correlation between the charge of the primary lepton (from the W decay) and the charge of the soft electron would imply, on average, an equal number of events in which these leptons have same sign (SS) and opposite sign (OS). We count the number of OS and SS events passing our selection and use the same-sign-subtracted sample to measure the Wc cross section. Background sources for this selection are mainly W+jets, Z+jets, multijet QCD, and Drell-Yan events, as well as a small contribution from diboson and single top events.

While, on average, the number of same sign and opposite sign events in $Wb\bar{b}$ and $Wc\bar{c}$ events should be equal (this is because we can either tag the q or the $\bar{q}$), we do expect some correlations

between the signs of the primary lepton and the soft electron in Drell-Yan events, and to a certain degree also in the W + light flavor sample and multijet QCD. This background comes mainly from events where $q\bar{q} \to l^+\nu X l^-\nu X$ and one lepton is mistaken as coming from the W decay while the other lepton is an SLT$_e$ tag.
Our observable quantity is the difference between the number of opposite sign and same sign events: $N_{os} - N_{ss}$. As always, the cross section is calculated using the following formula:

$$\sigma_{Wc} = \frac{N_{obs} - N_{bkg}}{\varepsilon \cdot \mathscr{A} \cdot \int \mathscr{L}} \tag{2.1}$$

- N_{obs} - number of events in data passing event selection ($N_{OS}^{data} - N_{SS}^{data}$).
- N_{bkg} - number of non-Wc events expected to pass event ($N_{OS}^{bkg} - N_{SS}^{bkg}$) selection, which is itself dependent on the assumed cross section
- ε - efficiency to tag Wc events (this is the efficiency for OS-SS events)
- $\mathscr{A}$ - kinematic and geometrical acceptance (same-sign-subtracted acceptance) for the lepton+jets selection (for pretag events)
- $\int L$ - total integrated luminosity

[3] is $P(tag) = P(tag_{OS}) + P(tag_{SS})$. We subtract the number of same-sign events from the number of opposite-sign events and use this difference to maximize the Wc acceptance and reduce background contribution in our selection.

3. Backgrounds

There are several different physics processes which might end up with a reconstructed signature passing our selection:

3.1 Backgrounds derived directly from Monte Carlo simulations

We estimate the backgrounds due to diboson and single top. The calculation of these backgrounds follows straightforwardly from the signal estimation, assuming the theoretical cross sections are adequate to predict these backgrounds. Single top events in the t-channel where a $W^-\bar{b}$ or a W^+b are produced can contribute to an excess of OS events. These backgrounds are small with respect to the other background sources as shown in Table 1.

3.2 Drell-Yan and Z+jets events

In Z+Jets events, if the Z decays leptonically, only one lepton could be reconstructed properly, and one of the associated jets could be SLTe tagged. Alternatively, both legs could be reconstructed, but the event still passes the Z veto and one leg is SLTe tagged. Yet another possibility is that the Z decays to $\tau\tau$, and a τ decays leptonically yielding a tight lepton.

In Drell-Yan events we have an off-shell Z or a virtual photon decaying to a lepton pair. The main contribution in the Drell-Yan background is from events in which the lepton radiates a high-energy photon, such that the lepton-photon pair is identified as a jet, while the other lepton is tagged with the soft lepton tagger.

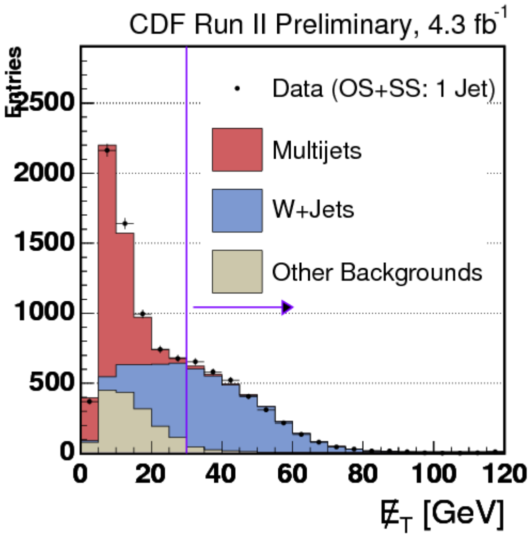

Figure 2: $\not\!\!E_T$ distribution in the anti-electron sample for OS+SS. The fit for these template is used to determine the QCD fraction in our selection.

3.3 Multijet QCD

Since multijet events will rarely have a high-P_T neutrino as the real cause of the missing energy, we separate these events from real W's by isolating excesses of events with low $\not\!\!E_T$.

We fit the missing energy distribution in the range 0-120 GeV. The templates of the $\not\!\!E_T$ shapes for each of the processes are derived from MC, except for QCD which is derived from "anti-electrons." Anti-electron events are events in the high-P_T electron samples in which the trigger electron fails two tight lepton selection requirements. We calculate the multijet-QCD fraction as the number of multijet QCD events predicted from the fit in the region $\not\!\!E_T >$ 30 GeV.

3.4 W + Jets

The dominant background to Wc production is the production of a W boson associated with jets. The theoretical prediction of such a process is difficult because the next-to-leading-order (NLO) corrections are large compared to the leading order (LO) calculation.

The W+jets contribution is estimated using a data-driven method: we calculate the expected number of W+jets events before applying the soft electron tagging selection. We do this by subtracting the predicted number of events from each of the other processes passing the same selection, and assume that the remained events come from W+jets production. To this number we apply the tag rate for this process which gives us the predicted number of tagged events.

In order to estimate the tag rate for such events, we evaluate the heavy flavor fractions in W+jets, the fraction containing real bottom and charm jets. These quantities are measured at leading order in a Monte Carlo sample, which specifically takes into account $Wb\bar{b}$ and $Wc\bar{c}$ processes, and the overall scale for $b\bar{b}$ and $c\bar{c}$ is calibrated in generic jets. This scale is called the K-factor, and is primarily intended to cover a mis-estimate of $g \to b\bar{b}$ and $g \to c\bar{c}$ processes, which contribute largely to the heavy-flavor content of both W+jets and generic QCD.

process	N(OS-SS)	$\delta_{systematic}$(OS-SS)
$W+jets$	79.15	$\pm$9.3
$Z+jets$	32.50	$\pm$7.17
QCD	4.94	$\pm$0.06
Drell Yan	7.65	$\pm$1.83
WW	0.14	$\pm$2.17
WZ	19.33	$\pm$0.02
ZZ	0.16	$\pm$0.03
Single Top	1.19	$\pm$0.01
$t\bar{t}$	0.49	$\pm$0.05
total bkg	145.55	$\pm$13.88
W+charm	56.17	$\pm$5.12
$Data$	299 ± 55	

Table 1: Expected number of OS-SS events. The uncertainties are systematic only. The observed number in data using using 4.3/fb of integrated luminosity is listed in the last row with its statistical uncertainty, assuming Poisson statistics.

4. Wc Production Cross-Section - Results from the Data

After estimating the expected number of OS-SS background events, we can measure the excess from Wc signal events. The statistical uncertainty is the dominant one, and is estimated to be 7.1pb.

Sources of systematic uncertainties for this measurement are related to the SLT$_e$ tagging procedure itself, , the background uncertainties which derive from the theoretical or experimental production cross-sections, the W+jets HF K-factor, the QCD fit, the acceptance modeling, the jet energy scale, the amount of initial and final state radiation and the parton density functions. These sum up to a total relative systematic uncertainty fo 21.8%.

The Wc production cross section is now calculated from Equation 2.1. The same-sign-subtracted efficiency implicitly contains the MC estimated charge asymmetry of the Wc (measured to be $(43.5 \pm 0.017)\%$). This yields a measured Wc production cross section of $21.1 \pm 7.1(stat) \pm 4.6(syst)$ pb.

References

[1] hep-ph/9308370; U. Baur, F. Halzen, S. Keller, M.L. Mangano, K. Riesselmann

[2] The CDF Collaboraton, Phys. Rev. Lett. 100, 091803 (2008)

[3] http://huhepl.harvard.edu/theses/chou.pdf