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Observation of WW/WZ $\to \ell\ \nu$ + jets at CDF

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Summary. — We present the observation of WW+WZ production in the channel with an identified lepton and two jets in $4.3\,\text{fb}^{-1}$ of integrated luminosity collected by the CDF II detector in $p\bar{p}$ collsions at $\sqrt{s} = 1.96\,\text{TeV}$. The measurement uses a fit to the dijet mass to disentangle the signal from the large background. The significance of the result is found to be 5.24σ and the cross section is measured to be $18.1 \pm 3.3(\text{stat.}) \pm 2.5(\text{syst.})$ pb, in good agreement with Standard Model prediction.

PACS 14.70.Fm – W bosons.
PACS 14.70.Hp – Z bosons.
PACS 13.38.Be – Decays of W bosons.
PACS 13.38.Dg – Decays of Z bosons.

1. – Introduction

Measurements of heavy vector boson pairs (WW, WZ, and ZZ) are important tests of the electroweak sector of the Standard Model (SM). Deviations of the production cross section from SM predictions could indicate the presence of new particles or interactions [1]. Furthermore the topology of diboson events is similar to events where a Higgs boson is produced in association with a W or a Z, so diboson searches and measurements are useful tests of analysis strategies employed in Higgs searches.

WW and WZ production has been observed at the Tevatron in channels where both bosons decay leptonically [2]. In semileptonic modes, where one boson decays to two quarks, large backgrounds make the signal extraction more challenging. CDF recently reported the first observation of such semileptonic decays in a channel with two jets and large missing transverse energy [3].

We present observation of semileptonic diboson decays in a channel with an identified lepton and two jets [4]. The discrimiation of the signal processes is accomplished using a fit to the invariant mass of the two-jet system.

2. – Event selection

The data sample corresponds to $4.3\,\text{fb}^{-1}$ of $\text{p}\bar{\text{p}}$ collisions at $\sqrt{s} = 1.96\,\text{TeV}$ collected by the CDF II detector, which is described in detail elsewhere [5]. It has been collected using trigger paths requiring a central electron (muon) with E_T (p_T) $> 18\,\text{GeV}$. Offline Events are selected requiring an electron or muon candidate with $p_T > 20\,\text{GeV}$ and $|\eta| < 1.0$(1) and two or more jets with $E_T > 20\,\text{GeV}$. Jets are clustered using a fixed-cone algorithm with radius $\Delta R = \sqrt{\Delta\eta^2 + (\Delta\phi^2)} = 0.4$ and their energies are corrected for detector effects. Furthermore we require the dijet vector boson candidate to have $p_T > 40\,\text{GeV}/c$. As a result of these selection criteria, the M_{jj} distribution for background is smoothly falling in the region where the signal is expected to peak. The invariant mass of the dijet vector boson candidate, M_{jj}, is evaluated from the two most energetic jets that are required to be be separated by $|\Delta\eta| < 2.5$. Several event vetos are imposed to reduce background levels and achieve good agreement between data and simulation. We reject events containing dilepton pairs consistent with the decay from a Z boson. We impose additional requirements to reduce the level of background due to QCD multijet events. These events will enter our sample if a jet fakes an electron or muon and mismeasurement leads to large $\not\!\!E_T$ (see footnote (1)). To reduce this contribution that is hard to model we select events with $\not\!\!E_T > 25\,\text{GeV}$ and $M_T(\text{W}) > 30\,\text{GeV}/c^2$ where $M_T(\text{W})$ (see footnote (1)) is the transverse mass of the lepton-$\not\!\!E_T$ system.

3. – Backgrounds

The dominant background to the diboson signal is W+jets production where the W decays leptonically. Smaller but non-negligible backgrounds come from QCD multijet, Z+jet, $\text{t}\bar{\text{t}}$, and single top production. The modeling for all processes except QCD multijet events is provided by event generators and a GEANT based CDF II detector simulation. Pythia [6] is used to model WW, WZ, and $\text{t}\bar{\text{t}}$ events. The W/Z+jets backgrounds are modeled using the fixed-order generator Alpgen [7] interfaced with the pythia parton showering framework. The QCD background is modeled using data events passing loosened lepton requirements. The normalization of WW, WZ, Z+jets, $\text{t}\bar{\text{t}}$, and single top backgrounds is estimated using predicted or measured cross sections and efficiencies derived from simulation. The normalization of the QCD background is estimated by fitting the $\not\!\!E_T$ spectrum in data to the sum of all contributing processes, where the QCD and W+jets normalizations float in the fit. While this fit provides an initial estimate of the W+jets normalization, this normalization is a free parameter in the final fit used to extract the diboson cross section.

4. – Fit technique

On data, we estimate the signal fraction by performing a χ^2 fit to the dijet invariant mass separately for the high p_T muon and electron samples. Five M_{jj} template

(1) We use a cylindrical coordinate system with its origin in the center of the detector, where θ and ϕ are the polar and azimuthal angles, respectively, and pseudorapidity is $\eta = \ln\tan(\theta/2)$. The missing E_T ($\vec{\not\!\!E}_T$) is defined by $\vec{\not\!\!E}_T = -\sum_i E_T^i \hat{n}_i$, where $\hat{n}_i$ is a unit vector perpendicular to the beam axis and pointing at the ith calorimeter tower. We define $\not\!\!E_T = |\vec{\not\!\!E}_T|$. The transverse mass of the W is defined as $M_T(\text{W}) = \sqrt{2p_T^l \not\!\!E_T(1 - \cos(\Delta\Phi^{l\nu}))}$.

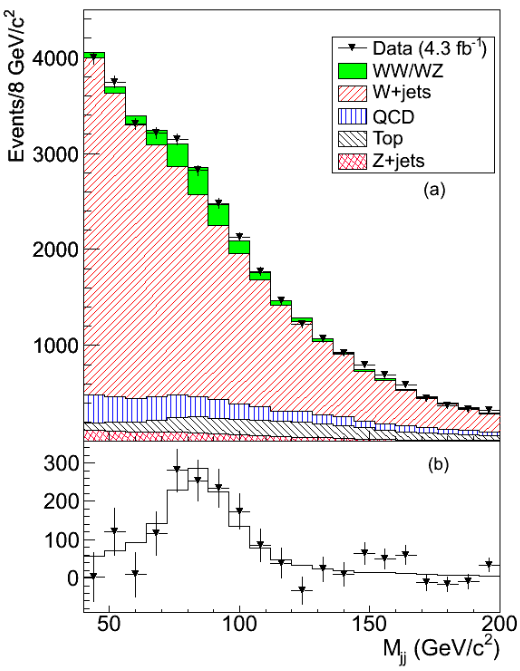

Fig. 1. – Dijet invariant-mass distribution compared to the fitted signal and background components (a) and the corresponding backgrounds subtracted distribution (b).

distributions are used in the fit. The Z+jets and $t\bar{t}$ contribution are constrained to the measured cross section with experimental error. The overall normalization of the W+jets template is a free parameter in the signal extraction. The template for the multi-jet QCD background is constrained by the fit to the $\not{E}_T$ described earlier. In addition, the global normalization of the sum of our signal and background models is a free parameter.

Figure 1 shows data superimposed on the fitted templates after the electron and muon samples are combined. We estimate in total $1582 \pm 275(\text{stat.}) \pm 107(\text{syst.})$ signal events.

The largest systematic uncertainties are due to the modeling of the W+jets and QCD shapes, about 8% and 6% respectively. The jet energy scale, which includes contributions both from the signal acceptance and from the shapes of the signal templates is about 6%. An uncertainty of about 5% due to initial and final state radiation and a 6% uncertainty on the integrated luminosity is also considered. Smaller contributions arise from PDFs, jet energy resolution, the factorization and renormalization scales used in the W+jets simulation, and trigger and lepton identification efficiencies.

We perform pseudo experiments to calculate the probability (p-value) that the background only discriminant fluctuates up to the observed result (observed p-value) and up to the median expected $s + b$ result (expected p-value). We observe a p-value of 8.56×10^{-8}, corresponding to a signal significance of 5.24σ, where 5.1σ were expected.

5. – Conclusion

In summary, we performed a search for WW/WZ in lepton neutrino plus jets final states looking for a resonance on top of a smoothly falling dijet mass distribution. The signal was observed with 5.24σ significance. The WW+WZ cross section is measured to be $18.1 \pm 3.3(\text{stat.}) \pm 2.5(\text{syst.})\,\text{pb}$ in good agreement with the NLO prediction of $16.1 \pm 0.9\,\text{pb}$.

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