Diboson Production at DØ

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We present high statistics measurements of diboson production in ppbar collisions at the DØ experiment in multiple channels, including ZZ → llll, Zγ → ννγ, WW → ℓℓνν, and WW/ZZ → ℓℓjj. These measurements both test physics beyond the standard model and demonstrate the sensitivity of hadron colliders to rare signals such as Higgs boson production.

1. Introduction

The study of diboson physics at the Tevatron allows us to probe gauge boson self-interactions that are a consequence of the non-Abelian nature of the SU(2)L ⊗ U(1)Y symmetry group. This is one of the least tested areas of the Standard Model.

Studies in this area provide a natural series of goals for detector sensitivity, probe fundamental details of the standard model electroweak sector directory and measurements at the Tevatron explore higher energies than LEP while providing access to some channels (e.g., WZ) not available there. New physics would be reflected in increased cross sections beyond standard model expectations.

Diboson physics also form backgrounds to many other interesting physics channels like Higgs, SUSY and ttbar, so understanding of the diboson physics can help studies at the LHC and Tevatron.

In this proceedings, we present the results from four analyses.

2. DØ Experiment

DØ is a multipurpose, hermetic detector. The interaction region is surrounded by a silicon microstrip detector and a fiber tracker within a 2 T superconducting solenoid magnet. There is a liquid argon-uranium calorimeter behind the magnet to measure the energy of most particles. The calorimeter is surrounded by three layers of muon detector, with a 1.8 T toroidal magnet after the first layer. It has pseudorapidity coverage of up to 3.2 for electrons and up to 2.0 for muons. The detector is completely described in the corresponding DØ NIM article. [1]

3. ZZ → llll Production

The SM prediction for the total ZZ production cross section in pp collisions at the Fermilab Tevatron Collider at √s = 1.96 TeV is σ(ZZ) = 1.4±0.1 pb [2]. The requirement of leptonic Z boson decays – each Z boson decay to either electron or muon pairs, resulting in final states consisting of four electrons (4e), four muons (4µ) or two muons and two electrons (2µ2e) – reduces the observable cross section, making its measurement rather challenging. The accumulation of integrated luminosities in excess of 3 fb−1 at the Fermilab Tevatron Collider and the development of highly optimized event selection criteria has now made possible the direct observation of ZZ production using a data set of 1.7 fb−1.

For the 4e channel, we require the measurement of four electrons with ordered transverse energies ET > 30, 25, 15, and 15 GeV, respectively, sorted by the number of electrons in the central detector in order to exploit differences in the QCD background, requiring at least two electrons in the central detector. For the 4µ channel, each measured muon must satisfy quality criteria based on scintillator and wire chamber information from the muon system, and have a matched track in the central tracker. We require that the four most energetic muons have ordered transverse momenta pT > 30, 25, 15, and 15 GeV, respectively. At least three muons in the event must be isolated. For the 2µ2e channel, the two most energetic electrons and muons in an event must have ET(pT) > 25, 15 GeV sorted by the number of electrons in the central detector. In all cases, the leptons have to be consistent with coming from a pair of Z bosons with one having a dilepton mass greater than 70 GeV and the other greater than 50 GeV, with opposite-charge, like flavor lepton pairing.

This selection provides for a clean signature with no other standard model background with four leptons. The small number of expected events means understanding of the background is important, the majority of which comes from Z/γ + jets, where the jets are misreconstructed as leptons. This background is sensitive to the number of electrons in the central calorimeter.

The predicted background is 0.14+0.03−0.02 and the pre-
predicted signal is 1.89 ± 0.08 with 3 events observed in the data as shown in Fig. 1. The likelihood of the background fluctuating to give the observed yield (p-value) is 4.3 × 10^{-8} corresponding to a significance of 5.3σ. When this result is combined with an earlier ZZ analysis in the same channel and a ZZ → ℓℓνν, we get a significance of 5.7σ and measure a cross section of 1.60 ± 0.63 (stat.)^{+0.16}_{-0.17} (syst.) pb. [3] This is in agreement with the theoretical expectation.

As stated, a single high \( E_T \) photon is required in the central calorimeter and a large missing transverse energy of greater than 70 GeV is also required to suppress multijet background. Backgrounds are further reduced by rejecting events with jets having \( p_T > 15 \) GeV which contribute to mismeasured missing \( E_T \) and the background from \( W \rightarrow ℓν \) and \( Z \rightarrow ℓℓ \) is reduced by vetoing on muons, isolated tracks and additional electromagnetic objects with a transverse momentum greater than 15 GeV. Non-collision background (e.g. muon from halo or cosmics undergoing bremsstrahlung) is handled using a pointing algorithm making use of the energy deposited in the calorimeter as well as measured tracks, where we assume the electromagnetic shower is initiated by photons, and require that the vertex pointed to by the energy is within 10 cm of the actual vertex, and that the distance of closest approach for the track is within 4 cm of the actual vertex.

The predicted background is 17.3 ± 2.4 and the predicted signal is 33.7 ± 3.4 with 51 events observed in the data. The likelihood of the background fluctuating to give the observed yield (p-value) is 3.1 × 10^{-7} corresponding to a significance of 5.1σ. We measure a cross section of 32.9 ± 9 (stat. + syst.) ±2(lumi.) fb. [3] This is in agreement with the theoretical expectation.

5. \( WW \rightarrow ℓℓνν \) Production

The SM prediction for the \( WW \rightarrow ℓℓνν \) production cross section in \( pp \) collisions is 12.0 ± 7 pb [2]. The measurement in this channel is performed with a data set of 1 fb^{-1}.

Signal selection requires two leptons from the same vertex consisting of \( ee \), \( eµ \) or \( µµ \) of opposite charge with at least one electron in the central calorimeter if appropriate and the leading lepton is required to have a transverse momentum of 25 GeV while the other has 15 GeV. Backgrounds are reduced using various additional cuts. The background from \( Z \rightarrow ℓℓ \) is reduced via optimized missing \( E_T \) for each channel, where the value is required to be greater than 44 GeV for \( ee \), 20 GeV for \( eµ \) or 35 GeV for \( µµ \). This is further refined by an invariant mass requirement in the \( ee \) channel and azimuthal angle requirements in the other two channels. To reduce top and \( W+jets \) backgrounds, we require a balanced event where \( q_T \) (the vector sum of the transverse momenta with the transverse missing energy) is required to be less than 20 GeV for \( ee \), 25 GeV for \( eµ \) or 16 GeV for \( µµ \).

We measure a cross section of 11.5 ± 2.1 (stat. + syst.) ± 0.7(lumi.) pb. [3] This is in agreement with the theoretical expectation. Distributions in \( p_T \) for the leading and trailing lepton are shown in Fig. 2.
6. $WW/WZ \rightarrow l\nu jj$ Production

The SM prediction for the $WW/WZ \rightarrow l\nu jj$ production cross section in $p\bar{p}$ collisions is $16.1 \pm 0.9$ pb \cite{2}. The measurement in this channel is performed with a data set of $1.1\,fb^{-1}$.

Signal selection requires one isolated lepton with $p_T > 20$ GeV in the central calorimeter, missing transverse energy greater than 20 GeV and two jets, the first with $p_T > 30$ GeV and the second greater than 20 GeV. Multijet backgrounds are reduced by requiring a transverse $W$ mass greater than 35 GeV, and backgrounds from $W$+jets, $Z$+jets, top etc. are reduced using a “Random Forest” multivariate discriminant.

The dijet mass peak extracted from data compared to the $WW=WZ$ MC prediction is shown in Fig. 3.

![Figure 3: A comparison of the extracted signal (filled histogram) to background-subtracted data (points), along with the ±1 standard deviation (s.d.) systematic uncertainty on the background. The residual distance between the data points and the extracted signal, divided by the total uncertainty, is given at the bottom.](image)

The likelihood of the background fluctuating to give the observed yield is $5.4 \times 10^{-6}$ corresponding to a significance of $4.4\sigma$. We measure a cross section of $20.2 \pm 4.4$ (stat. + syst.) $\pm 1.2(lumi.)$ pb. \cite{2} This is in agreement with the theoretical expectation.

7. Summary

We have shown measurements for four different diboson processes. This includes the first observation of $Z\gamma \rightarrow l\nu\gamma$ production, evidence for $WW/WZ \rightarrow l\nu jj$ production, a new measurement of $WW \rightarrow l\nu l\nu$ production and observation of $ZZ$ production. So far, everything agrees with standard model expectations. With over $6\,fb^{-1}$ now reconstructed, there will be more refined measurements in the future.

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