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ELECTROWEAK MEASUREMENTS AT THE TEVATRON

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Abstract

The increasing size of the data samples recorded by the CDF and DØ experiments at the Tevatron enables studies of a wide range of processes involving the electroweak bosons W and Z. Single boson production is now looked at in terms of differential cross sections such as rapidity or transverse momentum dependence. Diboson production cross-sections are several orders of magnitude smaller than single boson production cross-sections, but all combinations Wγ, Zγ, WW and WZ have been observed. ZZ production is expected at a rate just below the observation threshold with current data sample sizes, but this channel is expected to be accessible to the Tevatron experiments soon.

1 Introduction

Leptonic final states of W and Z boson decays exhibit a very clear experimental signature and pave the way for precision tests of the Standard Model beyond leading order and possible detection on non Standard Model contributions. These measurements can provide strong constraints to parton density functions.

The hadronic collision data recorded by the Tevatron experiments CDF and DØ as of early 2007 amount to more than $2\,\text{fb}^{-1}$ per experiment, about $1\,\text{fb}^{-1}$ each of which have been made available for electroweak physics analysis so far. While measurements of the total production cross-section of single W or Z bosons were already performed on much smaller size samples, the current data set allows for a much more in-depth analysis of the production process by measuring differential cross-sections. Also, most diboson production processes are now experimentally accessible despite their lower cross-section. In the following, we will summarise the typical W and Z selection procedure applied by the CDF and DØ experiments, and then present recent electroweak results made available by both collaborations.

2 W and Z reconstruction

Both CDF and DØ follow a fairly standard path for boson reconstruction, with only minor variations e.g. in cut thresholds between the different experiments or different analyses from the same collaboration.

Electrons are identified from calorimeter clusters that pass shower shape requirements and have a transverse momentum in excess of typically 20 GeV. Isolation cuts are applied to remove background from fake electrons and electrons in jets. Both DØ and CDF perform their reconstruction separately in the central barrel calorimeters and their forward calorimeters, while not using data from the intermediate region where modelling of the detector response is more difficult.

Muon reconstruction is based on signals identified in the muon detectors or calorimeters. In cases where efficiency is most important, CDF also includes tracks without associated muon or calorimeter signal in their muon selection. A transverse momentum threshold around 20 GeV is applied, and the muon candidates are required to be isolated in the tracking system and/or calorimeter to remove background from muons from heavy quark decay. The pseudorapidity coverage of muons used in the CDF analyses is restricted to $|\eta| \leq 1.1$–1.2, whereas DØ has muons in the range up to $|\eta| \leq 2$ at their disposal.

Tau leptons are not treated separately. Leptonically decaying taus are implicitly included in the electron and muon selections.

Leptonic W boson decays involve a neutrino, which is exploited for the reconstruction by requiring missing transverse energy of typically at least 20 GeV in candidate events. CDF requires the missing momentum vector to be isolated.

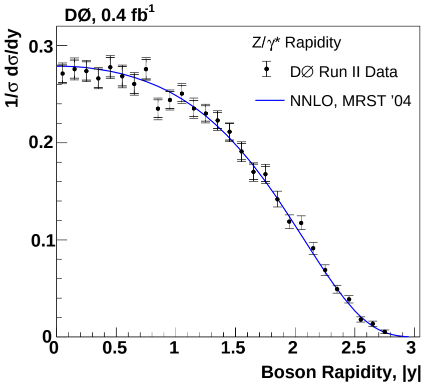

Figure 1: *Z boson rapidity distribution observed by DØ. This recently published 0.4 fb*$^{-1}$ *result* $^{1)}$ *is expected to be followed up by a 1 fb*$^{-1}$ *result soon.*

3 Differential Z cross-sections

Leptonic Z decays can be reconstructed fully and therefore provide the laboratory of choice for studying the intricacies of single electroweak boson production processes, despite the cross-section being an order of magnitude smaller than that of W production. The sample of reconstructed Z bosons collected at the Tevatron is large enough to investigate the dependence of the production cross-section on quantities such as Z rapidity and Z transverse momentum distribution.

The Z rapidity distribution is especially interesting in the forward region, where it provides constraints for parton density functions at low momentum fraction x and large momentum transfer Q^2, as well as at large x. Both DØ $^{1)}$ and CDF $^{2)}$ do this measurement in the Z→ee channel due to the larger η coverage of the calorimeter compared to the muon system, $|\eta| <3.2$ at DØ, $|\eta| <2.8$ at CDF. The observed distributions are compared to NNLO predictions (MRST '04, CTEQ6.1) and found to be in good agreement, as demonstrated for example in Fig. 1.

DØ also measures the transverse momentum distribution of Z bosons $^{3)}$. This distribution is very sensitive to higher order effect because there is no leading order contribution to Z transverse momentum. Prediction of this distribution requires resummation. Although the current revision of the measurement is not yet able to distinguish between different calculations, good agreement is found with the available predictions, and the sensitivity of the analysis to model differences is expected to be improved on a short time scale.

	exp.	sample	evts	prediction (SM, in pb)	measured cross-section (pb)
Wγ (μ)	CDF	1.1 fb^{-1}	855	19.3 ± 1.4	19.11±1.04(stat)±2.40(syst)±1.11(lum)
	DØ	1 fb^{-1}	245	3.21 ± 0.08	3.21±0.49(stat+syst)±0.20(lum)
Wγ (e)	DØ	1 fb^{-1}	389	3.21 ± 0.08	3.12±0.49(stat+syst)±0.19(lum)
Zγ	CDF	1.1 fb^{-1}	390	4.7 ± 0.4	4.9±0.3(stat)±0.3(syst)±0.3(lum)
	DØ	1 fb^{-1}	387	4.2 ± 0.4	4.51±0.37(stat+syst)±0.27(lum)
WW	CDF	0.8 fb^{-1}	95	12.4 ± 0.8	13.6±2.3(stat)±1.6(syst)±1.2(lum)
WZ	CDF	1.1 fb^{-1}	16	3.7 ± 0.3	$5.0^{+1.8}_{-1.4}$(stat)±0.4(syst)
	DØ	1 fb^{-1}	12	3.7 ± 0.3	$4.0^{+1.9}_{-1.5}$(stat+syst)
ZZ	CDF	1.1 fb^{-1}	1	1.4 ± 0.1	<3.8 (95% C.L.)

Table 1: *Overview of diboson production cross-section measurements discussed in this document. Predictions are as quoted in the respective analysis write-up. Analysis of different kinematic regions leads to different cross-section predictions for the same channel. In particular, DØ uses a very stringent FSR veto cut in their Wγ analysis, whereas CDF does not.*

4 Diboson production

Production processes of gauge boson pairs takes place at much lower cross-sections than single W or Z production. While we expect of the order of 100,000 reconstructed Z bosons per experiment per leptonic channel in one femtobarn of data, the expected yield for diboson processes extends down to about one event per femtobarn for ZZ production. Main emphasis of diboson reconstruction at this stage is therefore establishing signals and measuring the absolute absolute cross-section.

Very interesting results can be obtained from a measurement of the Zγ production rate. Since there are no ZZγ or Z$\gamma\gamma$ vertices in the Standard Model, Zγ combinations can only be produced by initial state or final state radiation. Any additional contributions would indicate new physics. CDF 4) and DØ 5) investigate Zγ production in Z→ee final states with a photon of at least 7 GeV. Photons from initial state and final state radiation can be distinguished by looking at the three-body eeγ mass in addition to the ee mass. Both experiments find agreement of the observed production rate with Standard Model predictions, and in particular no deviation from the expectation is observed at large photon transverse energies or in the ISR/FSR distributions.

Wγ production does have a leading order contribution. Both experiments measure cross-sections in good agreement with the standard model prediction. CDF 4) does this measurement in the W→ $\mu\nu$ channel, whereas DØ 6) uses both electron and muon final states and employs a very stringent final state radiation veto by requiring the Wγ three-body mass to exceed 110 GeV. DØ increases sensitivity to anomalous couplings by studying the charge signed rapid-

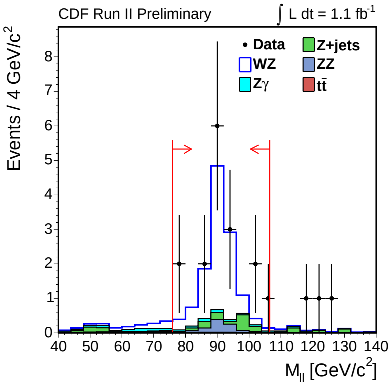

Figure 2: *Dilepton mass distribution of CDF WZ candidate events.*

ity difference $Q_\ell \times [y(\gamma) - y(\ell)]$, which is expected to vanish at zero for the Standard Model. This measurement will clearly unfold its full potential once larger data samples are available.

The production rates of massive boson pairs WW, WZ and ZZ are predicted to spread over an order of magnitude in a similar range as other important processes such as top quark pair production. While the signal of WW production has been clearly established (see 7) for a recent CDF measurement), the WZ state is just barely accessible to observation now. All combinations of electrons and muons in the final state are considered to maximise reconstruction efficiency. CDF 8) finds 16 WZ candidates in their approximately $1\,\mathrm{fb}^{-1}$ data sample (see Fig. 2), with an expected background contribution of $2.65 \pm 0.28 \pm 0.33 \pm 0.09$ events. This six standard deviation excess above the background expectation constitutes the first observation of the WZ channel. DØ 9) did a similar analysis, but due to a combination of various small effects their signal of 12 events including 3.61 ± 0.20 expected background events remains below the formal threshold for an observation. Both experiments do measure cross-sections in good agreement with the Standard Model.

The lowest end of the diboson production cross-section spectrum, ZZ production with an expected Standard Model cross-section of 1.4 ± 0.1 pb is hardly accessible to the Tevatron experiments so far. CDF 10) performed a search for this channel, finding one candidate event where approximately two are expected on average. They can therefore quote a cross-section upper limit of 3.8 pb at 95% C.L. It is reasonable to expect that the ZZ channel will be observed at the Tevatron once its full Run II dataset is becoming available.

An overview over recent diboson results is given in Table 1.

5 Discussion

Leptonic final states of W and Z bosons are fairly clear signatures even within the large background associated with hadron colliders. High cross-section processes like single W or Z production therefore provide an ideal laboratory for precision studies of parton density functions. Rare electroweak processes like production of massive boson pairs can already be identified down to cross-sections smaller than top quark pair production. While we can realistically expect to observe signatures like Z pairs (predicted at 1.4 ± 1 pb) at the Tevatron with a 4–8 fb^{-1} data sample per experiment, it seems unlikely that signals much smaller than that can be identified directly, such as a hypothetical Standard Model H→WW contribution at an expected cross-section another order of magnitude below that of ZZ production.

6 Acknowledgements

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    see *http://fcdfwww.fnal.gov/physics/ewk/2007/ZZ/ZZ_comb_public_note.ps*
    for a post-conference update incorporating also ZZ→ $\ell\ell\nu\nu$ candidates.