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Some aspects of W/Z boson physics at Tevatron

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The two experiments CDF and DØ at the Tevatron Collider at Fermilab have analyzed W/Z events produced in $p\bar{p}$ collisions to study and to test a variety of QCD predictions. The properties of W/Z production at Tevatron is reviewed and recent results on the transverse momentum distribution of W/Z bosons and the angular distribution of electrons from W-decays are presented.

1 Introduction

During the Run I period from 1992-96 the CDF [1] and DØ [2] detectors at Tevatron have each collected data from $p\bar{p}$ collisions at a center of mass energy of $\sqrt{s} = 1800$ GeV. The data sample corresponds to an integrated luminosity of about 120 pb^{-1} and each experiment was able to detect a large number of W/Z bosons in their leptonic decay channels.

W/Z-bosons at hadron colliders are produced via a Drell-Yan process primarily through the annihilation of $q\bar{q}$-pairs. The high energy scale of this process $Q^2 = M^2_{W,Z}$ makes it attractive to test perturbative QCD predictions in the production and decay of the bosons and to study the parton dynamics involved in the hard scatter of this process. The large statistics of the accumulated W/Z events allows further precise measurements of the electroweak vector boson properties.

2 W/Z production cross sections and W width

A large experimental background to W/Z-event signatures at the Tevatron comes from pure QCD multijet events, which limit the vector boson event selection to their leptonic decay channels only. Nevertheless, the leptonic event signatures $W \to l\nu$ and $Z \to l\bar{l}$ with branching ratios of 11% and 3% per leptonic mode respectively, are distinct and allow easy identification with

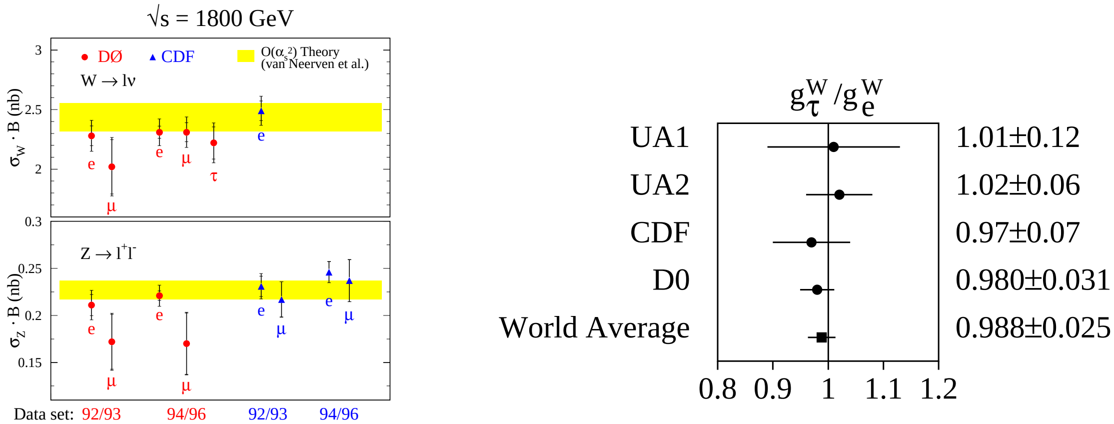

Figure 1: Left: The measured $\sigma \cdot BR$ for inclusive W and Z production. The shaded band is the $O(\alpha_s^2)$ theoretical prediction. Right: The measured ratio of g_τ^W/g_e^W to verify lepton universality to 3%.

high efficiencies and purities. In the e and μ channels one selects W events with one isolated high transverse momentum lepton ($p_T > 20 - 25\ GeV/c$) and large missing transverse energy ($E_T^{miss} > 20 - 25\ GeV$). For Z events, two isolated leptons with $p_T > 20 - 25\ GeV/c$ are required where the second lepton identification criteria may be loosened. The final event sample contains a small number of background events which are mainly due to QCD dijet events. This remaining background is typically $< 10\%$ for the W sample and $< 5\%$ for the Z sample in the central region.

Recent results from CDF and DØ for the measured inclusive cross section for W and Z production at Tevatron are shown in Fig. 1 left together with a QCD prediction based on a $O(\alpha_s^2)$ calculation [3]. The biggest experimental uncertainty in the cross section is the luminosity error of 4%, whereas all the other statistical and systematic errors are together 2 - 3%. Since the experiments are using different inelastic $p\bar{p}$ cross sections to determine their integrated luminosity, both Tevatron results can only be directly compared if a scaling factor between CDF and DØ is applied [a]. Note that the results in Fig. 1 left have not been rescaled. The agreement between CDF and DØ is very good and the measurements are consistent with the theoretical expectations. DØ has also updated the measurement of the W cross section times $W \to \tau\nu$ branching ratio using Run Ib data [4]. They obtain $\sigma_W \cdot BR(W \to \tau\nu)$=2220±90(stat)±100(sys)±100(lum) pb. By comparing this result with DØ 's published value of $\sigma_W \cdot BR(W \to e\nu)$ the ratio of the tau and electron electroweak charged current couplings to the W boson g_τ^W/g_e^W can be extracted. The result of $g_\tau^W/g_e^W = 0.98 \pm 0.031$ is shown in Fig 1 right together with results from other hadron collider experiments. A good agreement of the measurements with lepton universality is seen.

The uncertainty in the luminosity and some of the experimental errors in efficiency and acceptance cancel in the cross section ratio R:

$$R \equiv \frac{\sigma_W \cdot BR(W \to e\nu)}{\sigma_Z \cdot BR(Z \to e^+e^-)} = \frac{\sigma_W}{\sigma_Z} \cdot \frac{1}{BR(Z \to ll)} \cdot \frac{\Gamma(W \to l\nu)}{\Gamma(W)} \tag{1}$$

This ratio allows a precise, indirect measurement of the $W \to e\nu$ branching fraction BR($W \to e\nu$) by using the measured values of R, theoretical calculations within the Standard Model of σ_W/σ_Z [3] and of $\Gamma(W \to l\nu)$ [5] and finally a precise measurement of BR($Z \to ll$) from LEP [6]. The measured R-values from DØ and CDF using the whole data of Run Ia+b have been combined to give $R = 10.42 \pm 0.18$. The main sources of systematic errors are due to uncertainties in background, efficiencies, and electron energy scale. Using this combined value of R, the resulting branching

[a] A scaling factor has to be applied in the following way: $1.062 \cdot \sigma_{D0} = \sigma_{CDF}$

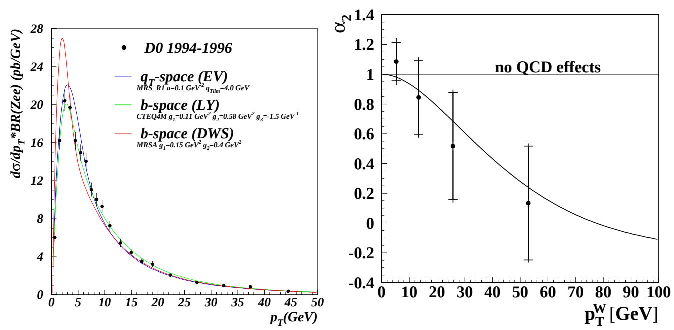

Figure 2: Left: The measured $d\sigma/dp_T$ for inclusive Z production. The different lines indicate various theoretical predictions. Right: The measured parameter α_2 as a function of p_T for the NLO QCD improved decay angle distribution of the W.

fraction for the W is $BR(W \to l\nu) = (10.43 \pm 0.25)\%$ and the indirect determination of the width of the W boson yields $\Gamma(W) = 2.171 \pm 0.052$ GeV. A significant part of the systematic error (1.5%) arises from the theoretical uncertainty on σ_W/σ_Z due to the choice of the renormalization scheme and electroweak radiative corrections. The agreement with the theoretical prediction can be used to set limits[7] on unexpected decay modes of the W bosons, such as W decays into supersymmetric charginos and neutralinos.

A direct measurement [8] of $\Gamma(W)$ has been made by the CDF experiment by using a binned likelihood fit to the W boson transverse mass (M_T) line shape in W events. A larger (smaller) value of $\Gamma(W)$ directly affects the M_T lineshape most prominently at high M_T and increases (decreases) the large M_T part of the spectrum. The CDF fit uses the region $100 < M_T < 200\ GeV$, where the Breit-Wigner line shape dominates over detector resolution effects and finds as a result for Run 1b $\Gamma(W) = 2.175 \pm 0.125(stat) \pm 0.115(sys)$ GeV for $W \to e\nu$ events and $\Gamma(W) = 1.78 \pm 0.195(stat) \pm 0.135(sys)$ GeV for $W \to \mu\nu$ events. Combining the e and μ results, with a common error 25 MeV, yields $\Gamma(W) = 2.04 \pm 0.11(stat) \pm 0.09(sys)$ GeV. The direct result is in good agreement with the indirect measurements and the SM prediction. Note, that the direct determination of $\Gamma(W)$ has much less model-dependent assumptions than the indirect measurements discussed above, but it is with the available data sets statistically limited.

3 The W and Z transverse momentum distribution

The experimentally observed non-vanishing transverse momentum of the W/Z bosons has been successfully described with a QCD improved parton model. Standard perturbative QCD allows a calculation of the differential cross section $d\sigma/dp_T$ by expanding in powers of α_s. This procedure works well when $p_T^2 \sim Q^2$ with $Q = M_{Z,W}$. The fixed order calculation diverges however, when $p_T \ll Q$. Correction terms proportional to $\alpha_s \ln(Q^2/p_T^2)$ become then significant in the perturbative series. To avoid such divergences, parts in the perturbative series coming from soft gluon emissions may be reordered and resummed[9]. This resummation technique extends the applicability of perturbative QCD to lower values of p_T, but encounters another more fundamental barrier when p_T approaches Λ_{QCD}. In order to account for non-perturbative contributions, a phenomenological form factor is introduced, which contains several parameters that must be tuned to data [10,11]. The resummation may be carried out in impact-parameter space via a Fourier transform, or in transverse momentum space. Both formalisms require a non-perturbative function to describe the low p_T region beyond some cut-off value.

DØ and CDF have published the p_T distribution of the W bosons [12] showing that the fixed order calculation has to be augmented by resummation terms in order to better describe the data.

The measurement at low p_T of the vector boson has the best resolution in the $Z \to ee$ case, so that such data are sensitive to the non-perturbative form factors in the different resummation models. High statistics data for $d\sigma/dp_T$ of the Z boson has recently become available [13]. Both experiments found a good agreement between data and current resummation calculations. DØ has also used their data to extract values of the non-perturbative parameters for a particular version of the resummation formalism [11]. The data are shown in Fig. 2 right along with various theoretical parameterization for the non-perturbative regime. With the enhanced precision of DØ 's data a more precise determination of the non-perturbative input parameters in the Landinsky-Yuan model was possible.

4 The decay angle distribution of the W

The emission of gluons and quarks in addition to the hard scattering of the colliding partons changes the angular decay distribution of the W/Z bosons into leptons. The NLO QCD corrections [14] modify the well-known $V - A$ decay angle distribution $(1 \pm \cos\theta^*)^2$ by introducing two new p_T-dependent parameters α_1 and α_2 resulting in $d\sigma/d\cos\theta^* \propto (1 + \alpha_1 \cos\theta^* + \alpha_2 \cos^2\theta^*)$, where θ^* is measured in a special rest frame of the W, the Collins-Soper [15] frame. Since the longitudinal momentum of the neutrino can not be measured, the transformation from the lab frame to the rest frame of the W is not explicitly calculable and the decay angle of the lepton θ^* is not directly measurable. To determine the decay angle distribution, DØ has exploited [16] the correlation between $\cos\theta^*$ and M_T of the W by using a Bayesian approach. This particular measurement by DØ is sensitive to the parameter α_2 only, since the W-charge and W-polarization remains undetected. The result is shown in Fig. 2 right together with a NLO QCD calculation and a naive $V - A$ expectation without QCD effects indicated as horizontal line. This is the first measurement of this QCD-related effect and the data prefer the NLO QCD calculation by $\approx 2.3\sigma$ over a calculation where no QCD effects are taken into account.

References

1. F. Abe *et al.*, *Nucl. Instrum. Methods* A **271**, 387 (1988).
2. S. Abachi *et al.*, *Nucl. Instrum. Methods* A **338**, 185 (1994).
3. R. Hamberg, W. L. van Neerven and T. Matsuura, *Nucl. Phys.* B **359**, 343 (1991); W. L. van Neerven and E. B. Zijlstra, *Nucl. Phys.* B **382**, 11 (1992).
4. B. Abbott *et al.*, *Phys. Rev. Lett.* **84**, 5710 (2000).
5. J. L. Rosner, M. P. Worah, T. Takeushi, *Phys. Rev.* D **49**, 1363 (1994)
6. L. Montanet *et al.*, *Phys. Rev.* D **54**, 1 (1996).
7. S. Abachi *el al.*, *Phys. Rev. Lett.* **75**, 1456 (1995).
8. T. Affolder *et al.*, submitted to *Phys. Rev. Lett.*, Fermilab-Pub-00/85E.
9. J.C. Collins, D.E. Soper, *Nucl. Phys.* B **193**, 381 (1981); *Nucl. Phys.* B **213**, 545E (1983); J.C. Collins, D.E. Soper, G. Sterman, *Nucl. Phys.* B **250**, 199 (1985).
10. C.T.H. Davies, B.R. Weber, W.J. Stirling, *Nucl. Phys.* B **256**, 413 (1985); P.B. Arnold, R.P. Kaufman, *Nucl. Phys.* B **349**, 381 (1991).
11. G.A. Landinsky and C.-P. Yuan, *Phys. Rev.* D **56**, 5558 (1997).
12. F. Abe *et al.*,*Phys. Rev. Lett.* **67**, 2937 (1991); B. Abbott *et al.*, *Phys. Rev. Lett.* **80**, 5498 (1998); B. Abbott *et al.*, submitted to *Phys. Rev. Lett.*, Fermilab-Pub-00/268E.
13. T. Affolder *et al.*, *Phys. Rev. Lett.* **84**, 845 (2000); B. Abbott *et al.*, *Phys. Rev. Lett.* **84**, 2792 (2000).
14. E. Mirkes, *Nucl. Phys.* B **387**, 3 (1992).
15. J.C. Collins, D.E. Soper, *Phys. Rev.* D **16**, 2219 (1977).
16. B. Abbott *et al.*, submitted to *Phys. Rev. D.*, Fermilab-Pub-00/228E.