W AND Z PHYSICS AT TEVATRON

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Recent measurements of W and Z boson properties at the Tevatron proton anti-proton collider are presented. A b-specific jet energy scale using $Z \to b\bar{b}$ signal has been extracted from CDF Run II data. The leptonic decay of Z boson in pairs of e^+e^- has been studied by both CDF and DØ experiments to measure the Z boson differential cross section. Leptonic decay of W boson has also been used, by DØ experiment, to measure the muon charge asymmetry.

1 Introduction

Studying the electroweak sector of the Standard Model (SM) is of major importance for the physic program of the CDF and DØ experiments for Run II at Tevatron. The large number of W and Z bosons, produced in this proton anti-proton collider operating at $\sqrt{s} = 1.96$ TeV, allow to measure and test precisely their properties. For instance differential cross section measurements of Z/γ^* boson leptonic decay or the study of lepton charge asymmetry in W decays provide useful knowledge of the parton distribution functions. The hadronic decays of W and Z bosons are of great interest as well. For example the hadronic decay of W boson is used in top mass analysis as a way to constain the jet energy scale. On the other hand a large-sized signal of $Z \to b\bar{b}$ decays allows a precise measurement of a b-quark specific jet energy scale, which is useful for all physic signal that involve b-jets.

We present here recent results on W and Z boson physics performed at CDF and DØ based on integrated luminosity ranging from 0.2 to 1 fb^{-1} .

2 Determination of a b-jet Energy Scale Using $Z \to b\bar{b}$ Decay

Extracting the $Z \to b\bar{b}$ resonnance allows both a precise measurement of the energy scale of b-quark jets and a determination of the b-jet energy resolution. The reduction of the uncertainty in the b-jet energy scale helps all precision measurements of the top quark mass, while a determination of the b-jet energy resolution is important for the search of a low-mass Higgs boson. The signal, most notably, opens the doors to a direct test of algorithms that attempt to increase the resolution of the b-jet energy measurement. These algorithms are a critical ingredient for the observability of the Higgs boson at the Tevatron if $M_H < 135$ GeV/c^2.

The jet energy scale (JES) is a factor which measures the discrepancy between the effect of detector response and energy corrections in real and simulated hadronic jets. When dealing with b-jets, however, one has to cope with several peculiarities of their fragmentation and decay properties. These effects have to be accurately modeled if one is to use a generic JES factor extracted from jets not containing heavy flavors to b-jets, such as those present in a $t\bar{t}$ decay.

This analysis is based on an integrated luminosity of 584 pb^{-1} collected by the Collider Detector at Fermilab (CDF II) from March 2004 to February 2006. A specific trigger was designed as a mean of acquiring a sizable amount of Z decays to pairs of b-jets, thereby providing a convenient calibration line for the energy measurement of b-jets.

A preliminary sample was selected by requesting events with two high transverse energy central jets ($E_t > 22$ GeV and detector pseudorapidity $|\eta_d| \leq 1.0$) and by requiring both leading jets to be taggable [a]. The number of data events surviving these preliminary requirements is 18,128,488. When both leading jets are required to be identified as b-jets (i.e "tagged") by the presence of secondary decay vertices using SECVTX algorithm [1], the number of selected events drops to 699,590.

Although the previous set of cuts allow to select events with low dijet invariant mass spectrum, which is crucial to observe a signal peak distinct from the background mass turn-on, the collected sample is largely dominated by QCD dijet background. However, because of the differences between $Z \to b\bar{b}$ process and QCD dijet production, requesting back to back events with low extra-jet radiation helps enhance the signal fraction. In order to reduce the background and initial and final state radiation processes, additional cuts on the azimuthal difference between the leading two jets, $\Delta\Phi_{12}$, and the tranverse energy of the third jet, E_t^3 were requested ($\Delta\Phi_{12} > 3.0$ and $E_t^3 < 15$ GeV). The number of selected events surviving all cuts (including tagging of the leading two jets) is 267,246 events.

The number of signal and background events, in selected data, and the b-jet energy scale factor, k, are measured simultaneously through and unbinned likelihood procedure. Pythia Monte-Carlo $Z \to b\bar{b}$ samples are used to construct a signal probability density function which has the dijet invariant mass and the b-jet energy scale as parameters. The mass shape of the background collected in the double tagged data, after the kinematical selection of events, is modeled using a data-driven method. A background enriched sample, orthogonal to the signal region, is selected and used to compute a tag rate shape, function of the dijet invariant mass. This ratio is then multiplied by the mass distribution of events with two taggable jets accepted by the kinematical cuts that define the signal region to construct the background template. Several background shape can be constructed depending on the choice of the background enriched region. The background model that best fits the sideband is used in an unbinned likelihood fit over the total dijet mass spectrum to estimate the b-JES factor and number of events of signal. The others possible background models are used to calculate the systematic errors related to background modeling.

The probability that observed data is described as an admixture of background events and $Z \to b\bar{b}$ events with a data/MC b-jet energy scale k is given by an unbinned likelihood function. The fit precision on k is improved by including a gaussian constraint on the expected number of events of signal (estimated from Monte-Carlo). Figure 1 shows the result of the unbinned likelihood fit to double tagged data. The goodness of this fit is estimated calculating the χ^2/NDF and gives 104/75. The final results, including all systematic calculations, are, for the b-jet energy scale factor:

$$k = 0.974 \pm 0.011(stat.)^{+0.017}_{-0.014}(syst.) = 0.974^{+0.020}_{-0.018}(stat + syst),$$

and for the number of fitted signal events:

$$N_{sig} = 5674 \pm 448(stat.)^{+1473}_{-570}(syst.) = 5674^{+1540}_{-725}(stat + syst) \text{ events.}$$

The large $Z \to b\bar{b}$ decay signal extracted from CDF II data allowed a measurement of the b-jet energy scale with a total precision of 2%. This result is relevant for b-jets in an energy range close to that of jets from Z decay, and additional studies are needed to exploit it in different signals involving b-jets.

[a] i.e to contain at least two tracks measured by the silicon tracker

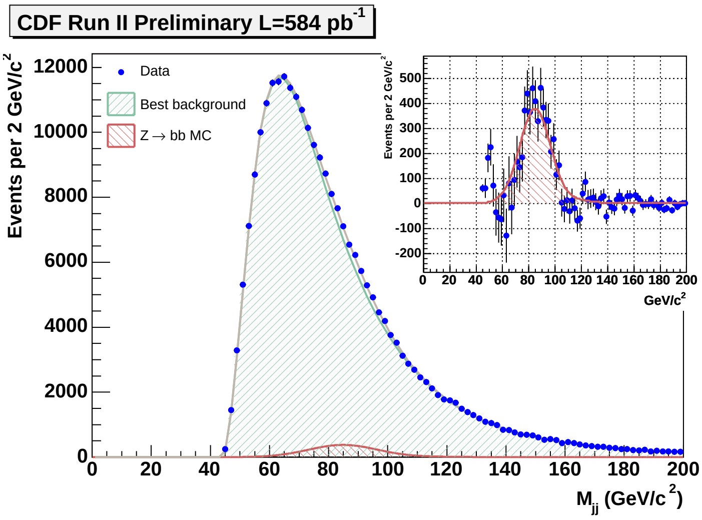

Figure 1: *Result of unbinned likelihood fit performed to double tagged dijets data (blue points). The data-driven background shape and Monte-Carlo signal p.d.f are shown respectively in green and red. The fit returns* 5674 ± 448 *events of signal and a b-JES of* 0.974 ± 0.011. *The inset on the upper right shows the data minus background distribution (blue points) and the signal shape (in red) normalized to the fitted number of events of signal.*

3 Z/γ^* Boson Rapidity Distribution

Kinematic distributions of Z/γ^* bosons produced in hadronic collisions provide a wealth of informations on the fundamental interactions involved. Measurement of the rapidity distribution and total cross section of Drell-Yan pairs in the Z/γ^* boson region provide a stringent test of QCD calculations in the leading order (LO) and next to leading order (NLO). At leading order, Z/γ^* bosons are produced through the annihilation of a quark and an anti-quark, with the partons in the proton and anti-proton carrying momentum fractions x_1 and x_2, respectively. The momentum fractions $x_1(x_2)$ are related to the rapidity (y) of the Z boson via the equation:

$$x_{1,2} = \frac{M_{Z/\gamma^*} e^{\pm y}}{\sqrt{s}} \tag{1}$$

where $\sqrt{s}$ is the center of mass energy and M_{Z/γ^*} the mass of the Z/γ^* boson. Both CDF and DØ measured the differential cross section distribution, $\frac{d\sigma}{dy}$, using dielectrons from Z/γ^* decays.

CDF used a dataset of 1.1 fb^{-1} collected using inclusive single central electron and dielectron triggers. Z bosons decays are selected as events with two high transverse energy electrons ($E_T > 20-25$ GeV). The dielectron data sample consists of three different topologies depending whether the electrons, from the e^+e^- pair, fall in the central ($|\eta| < 1.1$) or the plug calorimeters ($1.2 < |\eta| < 2.8$). After the cuts a total of 91,362 electron pairs are selected. The electron trigger efficiencies as a function of their transverse energy E_T are measured using the data. The overall trigger efficiency of the dielectron pairs versus rapidity is almost 100%. Geometric and kinematic acceptance are modeled using Pythia $Z \to e^+e^-$ event generator combined with GEANT simulation of the CDF detector. The total acceptance times efficiency is flat up to $y \sim 2.0$ and is non-zero up to $y = 2.9$.

The main source of background, for this analysis, is the QCD dijet background, which is estimated from data itself using the electron isolation energy[b] distribution. The background rates for electroweak processes (WW, WZ, $t\bar{t}$ inclusive, W inclusive) are estimated using simulation.

[b] The isolation energy is defined as the energy contained within a cone in (η,ϕ) of $\Delta R \leq 0.4$ around the electron minus the energy of the electron itself.

The differential cross section of electron pairs is defined as:

$$\frac{d\sigma(Z/\gamma^*)}{dy}(y) = \frac{N_{obs}(y) - N_{bg}(y)}{A \times \epsilon(y). \int Ldt} \tag{2}$$

where $N_{obs}(y) - N_{bg}(y)$ is the number of background-subtracted events, $A \times \epsilon(y)$ the combined acceptance and efficiency and $\int Ldt$ the total integrated luminosity. Figure 2 shows the $d\sigma(Z/\gamma^*)/dy$ distribution as a function of $|y|$. In this measurement the largest systematic uncertainty is associated with the measurement of the silicon tracking efficiency. The differential cross section measurement was compared to theory predictions and the NNLO calculation with NLO CTEQ6.1 PDF was found to be most consistent with the data. The total measured $Z/\gamma^* \rightarrow e^+e^-$ cross section, from integrating $d\sigma(Z/\gamma^*)/dy$, is $\sigma = 265.9 \pm 1.0 \pm 1.1$ pb.

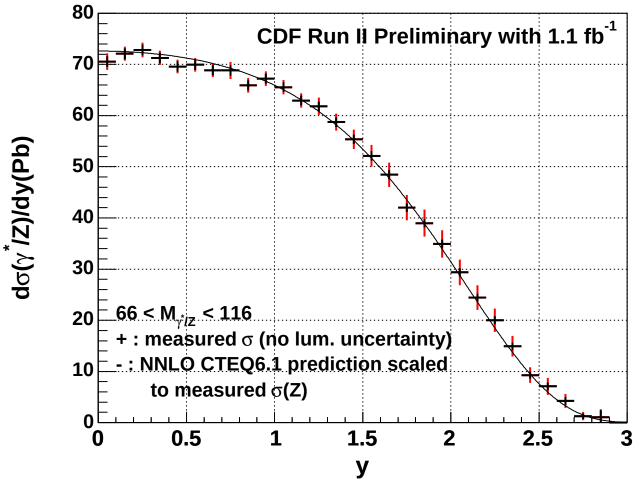

Figure 2: *Measured $d\sigma/dy$ for $p\bar{p} \rightarrow Z/\gamma^* \rightarrow e^+e^-$ in CDF II data. The crosses are the measurements and the solid line is the theory prediction.*

DØ experiment also performed a measurement of Z/γ^* boson rapidity distribution, using 0.4 fb^{-1} of data [2]. The normalized differential cross section was found to be consistent with MRST04 NNLO calculation.

4 Z Boson Transverse Momentum

A precision measurement of the Z boson transverse momentum provides a sensitive test of the theory for weak boson production, it also helps reduce the theoretical uncertainty on the precision W mass measurement. DØ performed a preliminary measurement of inclusive differential cross section as a function of Z boson transverse momentum in an invariant mass range betweem 70 and 110 GeV/c^2 using 960 pb^{-1} of collected data.

The selection criteria for candidate Z bosons decaying in e^+e^- pair requires two isolated electromagnetic (EM) clusters in the calorimeters that pass electron identication criteria, have high transverse momenta, and an invariant mass consistent with that of the Z boson. A total of 63,901 events are selected and identified as Z/γ^* candidates. Electron selection efficiencies are measured from the data, using the “tag and probe” method, and are parameterized in terms of the electron E_T and detector pseudorapidity, η_{det}.

ResBos and PHOTOS are used as the Z/γ^* event generator. A parameterized Monte Carlo simulation is used to simulate the effect of detector smearing and to include the measured electron identification efficiencies. The electron energy scale and resolutions are tuned using the Z data.

As in the previously described analysis, the main source of background come from QCD dijets. To estimate the size of this background, samples that contain mostly background events, are used to get the shape of the invariant mass distribution from this source. Other sources of background ($Z \to \tau\tau$ and dibosons) are studied using Monte Carlo and are found to be negligible.

The measured Z boson p_T spectrum is smeared due to detector resolution effects. To be able to compare with theory directly, the detector effects are first unfolded. The largest uncertainty on the unfolded Z p_T spectrum arise from the dependence of the efficiencies of the lepton identification requirements on the boson transverse momentum. The $\frac{d\sigma}{dp_T}$ distribution with both statistical and systematic uncertainties is shown in Figure 3. The data are compared to theoretical prediction and shown to be in good agreement.

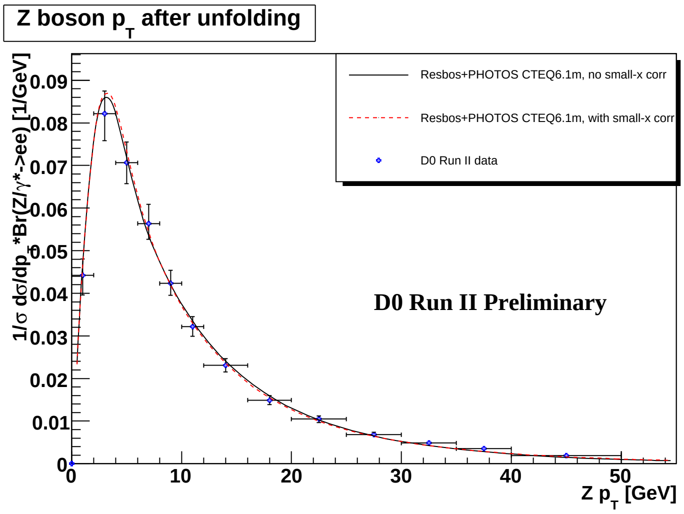

Figure 3: *Unfolded Z boson p_T distribution. The uncertainty contains both statistical and systematic uncertaintites.*

5 W Boson Charge Asymmetry

On average, the u-quark in the proton carries a larger fraction of the proton's momentum than the d-quark. This implies that at production, a $W^{+(-)}$ boson is typically boosted in the $p(\bar{p})$ direction. This leads to a charge asymmetry, as a function of the W boson rapidity, y_W. It is difficult to measure the W^{+-} rapidity due to the fact that the longitudinal momentum of the neutrino from the W decay cannot be measured directly. However the same information can be accessed by measuring the charge asymmetry of the W boson decay products. The lepton charge asymmetry is a convolution of the W production charge asymmetry and the asymmetry from the (V-A) decay. The lepton asymmetry can thus be used to probe the parton distributions. Both the DØ (muon channel) and CDF (electron channel) collaborations have measured the lepton charge asymmetry, defined as:

$$A(y) = \frac{N^+(y) - N^-(y)}{N^+(y) + N^-(y)}. \tag{3}$$

The main experimental challenge is to keep the lepton-charge misidentication rate low ($\sim$0.01% for DØ muon channel), and to understand possible charge-dependencies of selection efficiencies.

The DØ measurement is based on $\int Ldt \simeq 230$ pb^{-1} of recorded data. Good $W \to \mu\nu$ candidates are selected by requiring events with a high transverse momentum muon ($p_T > 20$ GeV), significant missing transverse energy ($\not\!\!E_T > 20$ GeV) and large W transverse mass ($M_T >$

40 GeV). After all selection cuts 189,697 W candidates are selected in the data. The largest source of contamination in the sample comes from electroweak backgrounds ($Z \to \mu\mu$, $W \to \tau\nu$, $Z \to \tau\tau$). These backgrounds are estimated using Monte Carlo samples. The other major source of contamination comes from the multijet background (semi-leptonic decay) and is estimated from data.

The final result of the DØ measurement, is given in figure 4. Even though the uncertainties on the experimental points are dominated by the finite data-sample-size, some sensitivity to PDF's is already obtained (assuming the W boson decays according to the standard model). Thus, with more data, this measurement will constrain the PDF's.

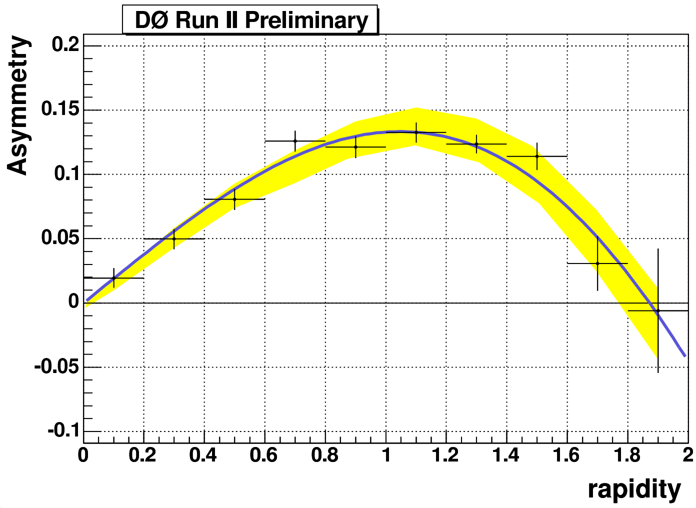

Figure 4: *Measured and predicted muon charge asymmetry, as a function of muon rapidity. The theoretical curves are based on NLO calculations (RESBOS and CTEQ6.1M PDFs).*

6 Conclusions

A large signal of $Z \to b\bar{b}$ decays from Tevatron collider data has been successfully extracted. This signal allowed to perform the first precise measurement of a b-specific jet energy scale. This measurement is of interest for all signal involving b-jets (top quark mass measurements, Higgs boson searches).

On the other hand, precision measurements of differential W and Z boson production cross sections have been performed. The results agree well with standard model predictions. Measurements of lepton charge asymmetries as a function of lepton rapidity are already sensitive to PDF's. In the near future, several times more data will be analyzed. This will provide a better determination of PDF's, which in its turn is important for reducing systematic uncertainties on, for example, the W boson mass measurement.

References

1. D. Acosta *et al.* (CDF Collaboration), *Phys. Rev.* D **71**, 052003 (2005).
2. V.M. Abazov *et al.* (DØ Collaboration), hep-ex/0702025, submitted to *Phys. Rev.* D.