Measurements of W+jet(s) and Z+jet(s) Production Cross Sections at CDF

Monica D'Onofrio[1] *

1- Institut de Fisica d'Altes Energies - IFAE
Barcelona - E08193 Spain

The Tevatron $p\bar{p}$ Collider is the highest-energy accelerator currently operational. At the beginning of 2007, the amount of collected data reached 1 fb^{-1}. In this contribution, results on W and Z boson production in association with jets are presented.

1 Introduction

Measurements on W and Z bosons production in association with highly energetic jets of hadrons are a fundamental part of the CDF physics program, since they constitute a major background for top quark physics (mainly W+jets) as well as in searches for new physics like Higgs and SuperSymmetry (*eg.* $Z \rightarrow \nu\nu$+jets irreducible background). The study of Boson+jets production provides a stringent test of perturbative QCD (pQCD) predictions, where parton-level NLO pQCD calculations are performed up to two partons in the final state. Furthermore, a significant effort is being made in the past years to build Leading Order Monte Carlo (MC) predictions for Boson+jets final states with large jet multiplicities. These predictions are based on parton-level LO Matrix Elements (ME) interfaced with Parton Showers (PS) where special prescriptions are necessary to properly match the final states and avoid double counting in the gluon radiation. Precise measurements on Boson+jet final states are necessary to validate the matching procedures.

2 Jet production in association to W bosons

The measurement of inclusive W+jets cross sections is based on an integrated luminosity of $0.32\,\mathrm{fb}^{-1}$ carried out by CDF. W boson candidates are identified via the presence of a high $\mathrm{P_T}$ electron and large missing transverse energy associated to the neutrino. The definition of the measured cross section is restricted to the region of phase-space where electron $\mathrm{P_T}$ is above 20 GeV/c, $\mathrm{P_T}$ of the neutrino is above 30 GeV/c, and the transverse mass of the reconstructed W is above 20 GeV/c^2. Jets are searched for using a cone-based algorithm with cone size R = 0.4 and are required to have transverse energy $\mathrm{E_T^{jet}} > 15$ GeV and pseudo-rapidity $|\eta^{\mathrm{jet}}| < 2.0$. The $W \rightarrow e\nu$ candidate events are finally classified according to their jet multiplicity into four inclusive n-jet samples.

The $W(\rightarrow e\nu)$+jets data sample contains background mainly from QCD and top pair production. QCD background is described with a data-driven technique, where a genuine multi-jets event sample is extracted selecting events that pass all kinematic requirements, but which fail one or more electron identification requirements. Other background contributions from top pair production, $W \rightarrow \tau\nu$, $Z \rightarrow ee$ and dibosons are estimated using Monte Carlo samples. The total background varies from 10% at low $\mathrm{E_T^{jet}}$ and low jet multiplicity to 80% at high $\mathrm{E_T^{jet}}$ and high jet multiplicity.

*On behalf of the CDF Collaboration

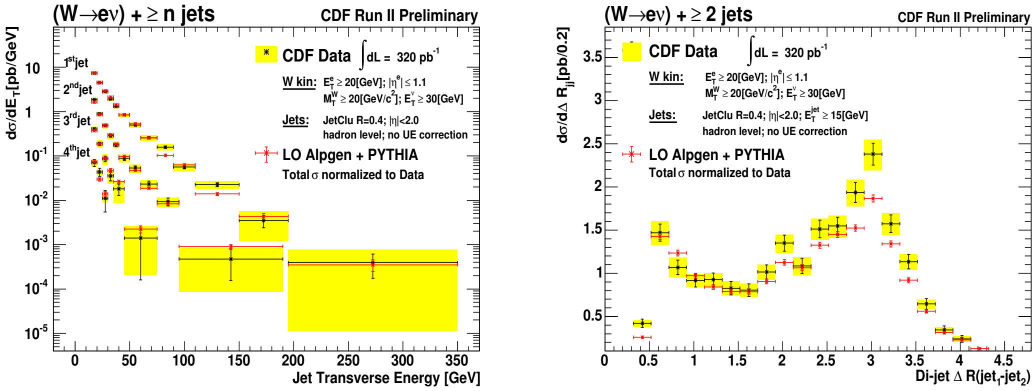

Figure 1: *Left: Differential cross section as a function of the* $\mathrm{E_T^{jet}}$ *of the* $\mathrm{n^{th}}$ *jet in inclusive* $W+\geq$ n − jet *production, compared to ME+PS predictions separately normalized to the measured inclusive cross section in each jet multiplicity sample. Right: Differential cross section as a function of* $\Delta\mathrm{R}$ *of the 2 leading jets in* $W+\geq 2$ *jet events.*

Figure 1 (left) shows the measured differential cross section, corrected at the hadron level, as a function of the transverse energy of the $\mathrm{n^{th}}$ jet in inclusive $W+\geq$ n − jet production. The shaded bands are the total systematic uncertainty in each measurement and are dominated by a 3% uncertainty on the jet energy scale. The measured cross sections are compared to LO Matrix Element plus Parton Showering MC predictions as determined using ALPGEN(v2)[1]+PYTHIA. The predictions are separately normalized to the measured inclusive cross section in each jet multiplicity sample, and provide a reasonable description of the shape of the measured $\mathrm{E_T^{jet}}$ spectra.

Figure 1 (right) shows, for $W+\geq 2$ jet events, the measured differential cross section as a function of $\Delta\mathrm{R_{jj}}$, where $\Delta\mathrm{R_{jj}}$ denotes the separation (in the η-ϕ space) between the two leading jets. ME+PS predictions normalized to the total cross section provide a reasonable description of the data.

3 Inclusive Z+jets cross section

The Z boson production cross section is 10 times smaller than the W boson cross section. However, with more than $1\,\mathrm{fb^{-1}}$ of data, precise differential measurements on $Z(\rightarrow ee)$+jets production are also possible, with the advantage that $Z \rightarrow ee$ is a clean and almost background free signal. CDF has measured the inclusive $Z(\rightarrow ee)$+jets cross section using $1.1\,\mathrm{fb^{-1}}$ of data. The measurement is performed in a well defined kinematic region of the jets and the Z boson decay products. Electrons must have $\mathrm{E_T^e} > 25\,\mathrm{GeV}$ and be in the range $66 < \mathrm{M_{ee}} < 116\,\mathrm{GeV/c^2}$, where one electron has to be in the central region of the calorimeter ($|\eta^e| < 1.0$) and the other can be either in the central or in the forward region ($1.2 < |\eta^e| < 2.8$). Jets are reconstructed using the MidPoint algorithm[2] with cone radius $\mathrm{R} = 0.7$. The jets are required to have $\mathrm{p_T^{jet}} > 30\,\mathrm{GeV/c}$, $|\mathrm{y^{jet}}| < 2.1$ and $\Delta\mathrm{R_{e-jet}} > 0.7$, where $\Delta\mathrm{R_{e-jet}}$ denotes the distance (y-ϕ) between the jet and each of the two electrons in the final state.

The $Z(\to ee)$+jets data sample contains background mainly from QCD-jets and W+jets processes and it is extracted from data. Other background contributions from $t\bar{t}$, $Z(\to ee)+\gamma$, dibosons and $Z(\to \tau\tau)$+jets final states are estimated using Monte Carlo samples. The total background in inclusive $Z(\to ee)+\geq$ N$_{\text{jet}}$ production varies between 10% to 14% as N_{jet} increases.

The measured cross section is corrected to the hadron level and compared to NLO pQCD predictions. The NLO pQCD prediction is determined using MCFM[3] and includes non-pQCD contributions. Non-pQCD contributions are computed using PYTHIA Tune A MC, and the difference between PYTHIA Tune A and PYTHIA Tune DW results are quoted as systematic uncertainty. Observables that are sensitive to the MC modeling, such as jet shapes and energy flows, have been measured and a good agreement was found between data and PYTHIA Tune A and DW predictions, making both PYTHIA Tune A and DW reliable tools to extract the parton-to-hadron corrections.

In Figure 2 (left) the measured integrated jet shape – defined as the fraction of transverse momentum of the jet contained inside a cone of radius r concentric to the cone of the jet (R) in events with exactly one reconstructed primary vertex – is compared to different MC predictions with different Underlying Event (UE) settings. Both PYTHIA Tune A and PYTHIA Tune DW provide a good description of the data. Data are also compared to a PYTHIA MC sample with no interaction between proton and antiproton remnants, producing jets significantly narrower than the data. Alternatively, one can test the UE activity by looking at the energy flow in the transverse plane away from the main jet direction. Figure 2 (right) shows the measured energy flows, using calorimeter towers with $|y| < 0.7$ where, event-by-event, $\phi = 0$ is defined along the direction of the momentum of the Z boson. At $|\phi| = \pi$ the measured distribution shows a prominent peak coming from the leading jet, while at $|\phi| = \pi/2$ the measured energy flow is dominated by soft UE contributions. Both PYTHIA Tune A and PYTHIA Tune DW (the latter not shown in the plot) provide a good description of the measured energy flow.

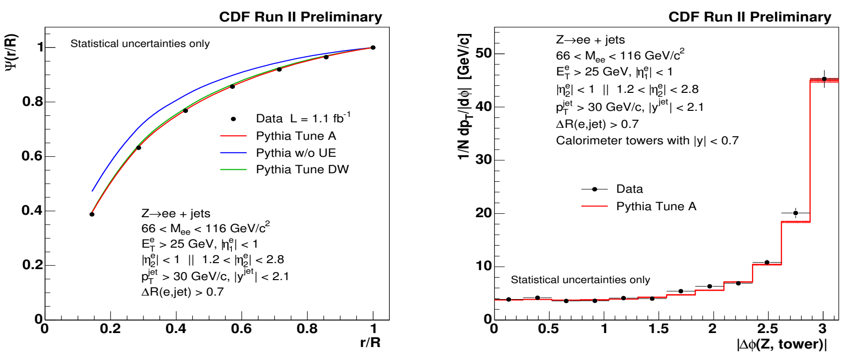

Figure 2: *Left: Integrated jet shapes in Z+jets events compared to different settings of the UE modeling. Right: Energy flow in the transverse plane in Z+jets events with respect to the Z boson direction ($\phi = 0$).*

Figure 3 shows the inclusive $Z(\rightarrow ee)$+jets cross section as a function of the transverse momentum of the jet, compared to NLO pQCD predictions. The shaded band is the total systematic uncertainty and it is dominated by a 3% uncertainty on the jet energy scale. The NLO pQCD predictions provide a good description of the measured cross section after non-pQCD corrections are included. The corrections for the non-perturbative contributions ($\mathrm{C_{had}}$) are shown in the bottom part of the plot. They account for up to 25% of the cross section at low $\mathrm{p_T^{jet}}$. The total cross section as a function of the inclusive jet multiplicity is shown in Fig. 4. The data are compared to LO and NLO pQCD predictions that include parton-to-hadron non-perturbative corrections. Good agreement is observed between data and NLO pQCD predictions. The plot also shows the ratio to the nominal LO prediction. An approximately constant NLO/LO k-factor is found for $\mathrm{N_{jet}} = 1, 2$ and the data suggests a similar factor for $\mathrm{N_{jet}} = 3$.

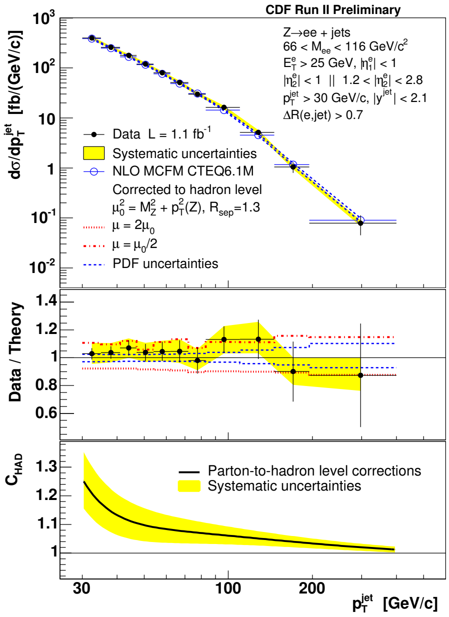

Figure 3: *Inclusive Z+jets cross section as a function of* $\mathrm{p_T^{jet}}$*, compared to NLO pQCD predictions and showing the non-pQCD contributions* ($\mathrm{C_{had}}$)*.*

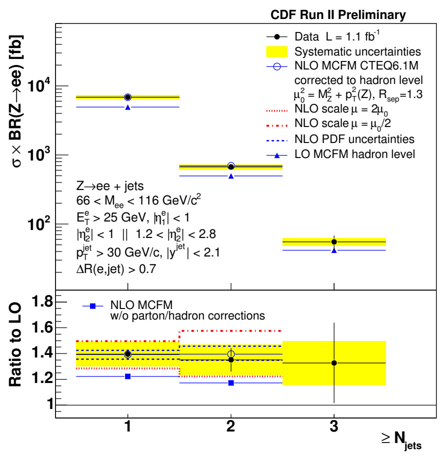

Figure 4: *Total cross section for Z(→ee)+jets production versus inclusive jet multiplicity compared to LO and NLO pQCD predictions.*

4 Conclusions

We have presented results on inclusive Boson+jets production in $p\bar{p}$ collisions at $\sqrt{s}$=1.96 TeV. The measurements are well described by ME+PS and NLO pQCD predictions.

5 Acknowledgments

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References

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[4] Slides: `http://indico.cern.ch/contributionDisplay.py?contribId=223&sessionId=6&confId=9499`