

## Z+jets Results from CDF

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The CDF collaboration has an interesting and comprehensive program on the study of jet production in association with a Z boson. These measurements are important because Z+jets events are a background in many searches of new physics and in particular Z+b jet represents the main and irreducible background for Higgs boson produced in association with a Z where the Higgs decays in two b quarks.

In this contribution the differential cross section of Z+jet production as a function of transverse momentum of the jet, jet rapidity and jet multiplicity and the Z+bjet cross section ratio with respect to the Z inclusive and Z+jet cross section are presented. The results are compared with the next-to-leading order predictions.

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## 1. Introduction

The production of jets in association with a Z boson at hadron colliders is a very important process to study because it permits to test the perturbative QCD predictions and in addition it represents an important background to many searches of new physics, for example Higgs and SUSY. For this reason dedicated measurements of Z+jet and Z+bjet cross sections are crucial to improve the understanding and the modeling of these processes.

## 2. Z+jet Cross section measurement

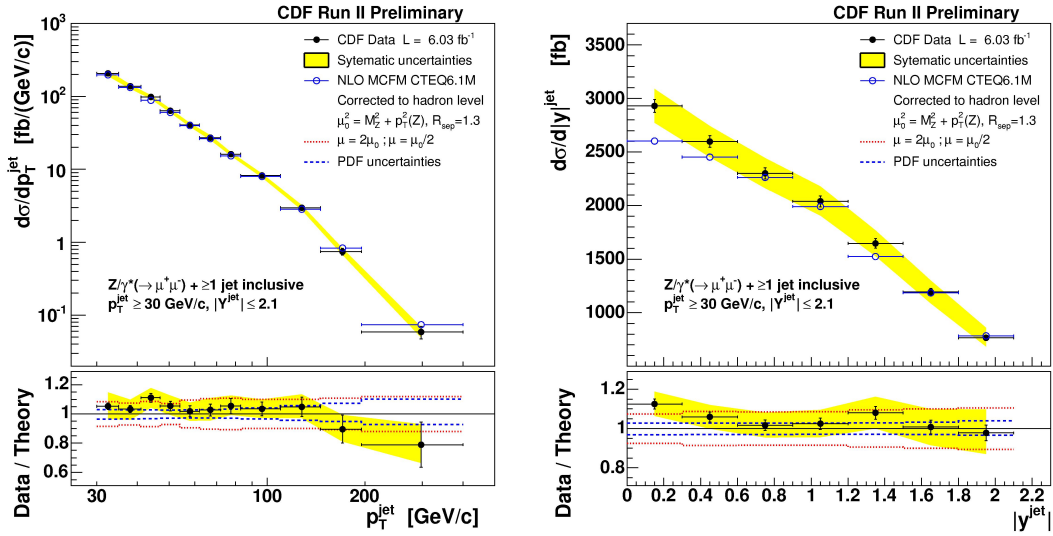
The CDF collaboration recently presented updated results for Z+jet in  $Z/\gamma^* \rightarrow \mu^+\mu^-$  muon [1] and  $Z/\gamma^* \rightarrow e^+e^-$  electron [2] channels. Here the measurement is presented separately for the two channels using  $6 \text{ fb}^{-1}$  of data. For both channels the same kinematics cuts are used and the measurements are defined in the same phase space.

For the muon channel the events are required to have two high  $p_T$  ( $p_T \geq 25 \text{ GeV}/c$ ) central ( $|\eta_\mu| \leq 1.0$ ) muons with an invariant mass between 66 and  $116 \text{ GeV}/c^2$ . The jets are reconstructed with the MidPoint [3] algorithm in a cone of 0.7 and are required to have  $p_T \geq 30 \text{ GeV}/c$  and  $|Y^{jet}| \leq 2.1$ . The background is estimated using data driven techniques and Monte Carlo programs. In particular QCD dijet, W+jets and decay in flight contributions are estimated with the data using same charge dimuon events. Backgrounds coming from  $t\bar{t}$ , diboson (ZZ, WW, ZW) are evaluated with Monte Carlo samples. The global contribution from background represents less than 10 %.

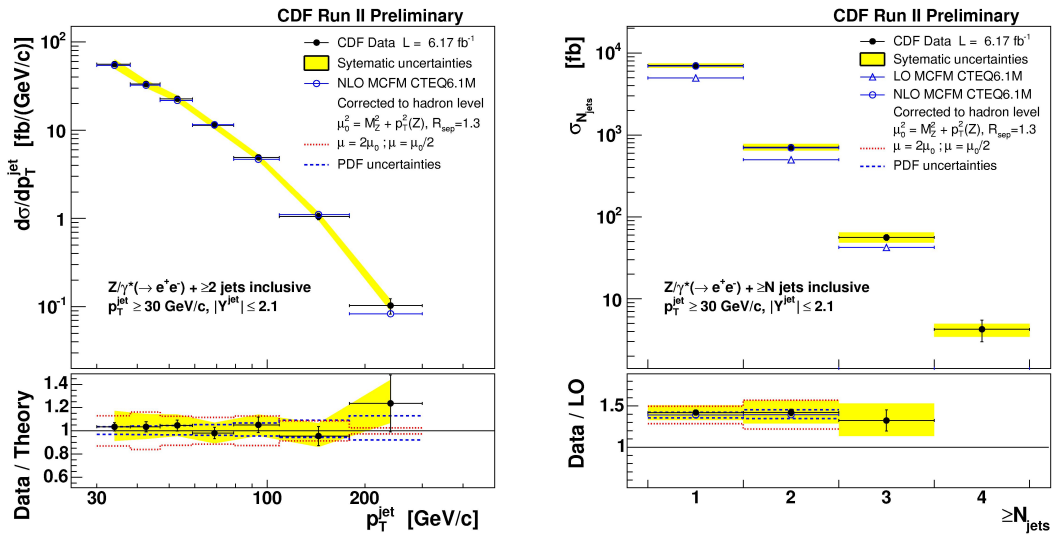
The measurement at calorimetric level is unfold back to hadron level to take into account unfolded resolution effects and the detector acceptance of  $Z \rightarrow l^+l^-$ . The unfolding is done using ALPGEN+PYTHIA Monte Carlo. The results are compared with next-to-leading order (NLO) predictions evaluated with MCFM and corrected for non perturbative effects (underling events and hadronization) using PYTHIA Tune A. All the differential cross section distributions (Figure 1) are in agreement with the theory. Main systematic uncertainty that affects this measurement is due to the uncertainty on jet energy scale and varies between 3-15 %. The re-normalization and factorization scale and PDF uncertainties are calculated for the theoretical predictions.

The measurements for Z+jet cross section in  $Z/\gamma^* \rightarrow e^+e^-$  channel was already published [4] and presented with  $1.7 \text{ fb}^{-1}$  of integrated luminosity, here an update of this measurement with  $6 \text{ fb}^{-1}$  is shown. The measurement is defined as for the muons, and differs only because in the electron channel one of the electrons can be reconstructed in the forward region of the detector ( $1.1 \leq \eta^e \leq 2.8$ ).

Figure 2 shows the good agreement between data and theoretical prediction also for this channel in the differential cross section for at least two jets as a function of the transverse momentum of the jet and as a function of jet multiplicity.



**Figure 1:** Measured inclusive jet differential cross sections as a function of jet transverse momentum in  $Z + \geq 1$  jet events and as a function of jet rapidity. Data (black dots) are compared to NLO predictions (open circles). The shaded bands show the total systematic uncertainty, except for the 5.8% luminosity uncertainty. The dashed and dotted lines indicate the PDF uncertainty and the variation with  $\mu_0$  of the NLO pQCD predictions, respectively.



**Figure 2:** Measured inclusive jet differential cross sections as a function of jet transverse momentum in  $Z + \geq 2$  jet events and as a function of jet multiplicity.

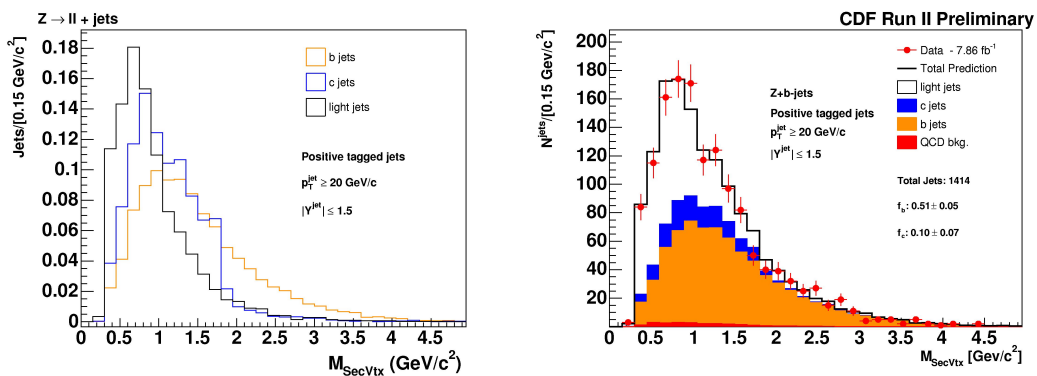
### 3. Z+b jet Cross section measurement

The Z+bjet cross section measurement at CDF was already published with  $2 \text{ fb}^{-1}$  of integrated luminosity [5]. Here an update of this measurement based on  $8 \text{ fb}^{-1}$  [6] is presented. It is performed as a per-jet cross section measurement ratio with respect to Z inclusive cross section and Z+jet cross section. This is done because in this way some systematics (luminosity uncertainty, lepton ID) are largely canceling in the ratio.

The events are required to have two high energy leptons (electrons or muons) with an invariant mass between 66 and  $116 \text{ GeV}/c^2$  and a central ( $|Y^{\text{jet}}| \leq 1.5$ ) high  $p_T$  ( $p_T \geq 20 \text{ GeV}/c$ ) jet clustered with MidPoint 0.7. For the  $Z/\gamma^* \rightarrow e^+e^-$  channel the same kinematics cuts to reconstruct the Z as in the Z+jet analysis that has been presented before, are used, while for the  $Z/\gamma^* \rightarrow \mu^+\mu^-$  the selection is improved to optimize the significance. This is done using cuts on the outputs of two artificial neural networks trained to separate QCD backgrounds from real muons. The improvement on the Z acceptance is  $\sim 30 \%$ .

The identification of the b jet is done with a Secondary Vertex Tagger that identifies jets with a secondary vertex reconstructed inside, taking the advantage of the large b life time. Since the tagged sample is not pure, the b quark composition is extracted from a fit to the mass of a displaced secondary vertex reconstructed within the jet (Figure 3). The measurement is unfolded back to the hadron level to the total phase space and normalized to the Z inclusive and Z+jet cross section. The main systematics is coming from the variation of the template shape due to a track reconstruction inefficiency and due to b-tagging efficiency uncertainty.

The results obtained is  $\frac{\sigma(Z+b)}{\sigma(Z)} = 2.84 \pm 0.29 \pm 0.29 \times 10^{-3}$  and  $\frac{\sigma(Z+b)}{\sigma(Z+\text{jet})} = 2.24 \pm 0.24 \pm 0.26 \times 10^{-2}$ . These are compared (Table 1) to NLO predictions evaluated with MCFM and corrected for non perturbative effects, at different re-normalization scales. Within the uncertainty the measured cross section is in agreement with the theory, but a large uncertainty is present due to the choice of the re-normalization scale.



**Figure 3:** The templates for the mass of a displaced secondary vertex used for fitting the data. These templates are built with ALPGEN+PYTHIA Monte Carlo tools. On the right the result of the fit.

	Measured	NLO $Q^2 = m_Z^2 + p_{T,Z}^2$	NLO $Q^2 = \langle p_{T,jet}^2 \rangle$
$\frac{\sigma(Z+b)}{\sigma(Z)}$	$2.84 \pm 0.29 \pm 0.29 \times 10^{-3}$	$2.3 \times 10^{-3}$	$2.8 \times 10^{-3}$
$\frac{\sigma(Z+b)}{\sigma(Z+jet)}$	$2.24 \pm 0.24 \pm 0.26 \times 10^{-2}$	$1.8 \times 10^{-2}$	$2.2 \times 10^{-2}$

**Table 1:** The results of per jet Z+bjet cross section ratio with respect to Z inclusive and Z+jet cross section. These results are compared with the predictions done at NLO with MCFM at different re-normalization/factorization scales.

#### 4. Summary

In this report, measurements of Z+jet differential cross section have been presented in the electron and in the muon channels with  $6 \text{ fb}^{-1}$  of data. It was found that the data is well described by NLO pQCD predictions. The combination of the muon and the electron channel and the distributions in the 3-jet multiplicity bin works in progress.

It has been also reported the per-jet Z+bjet cross section ratio measurement with respect to the Z inclusive and Z+jet cross section. Results are in agreement with NLO predictions and their uncertainty has been reduced to  $\sim 15\%$ .

#### References

- [1] CDF Collaboration, *CDF Conference Note 10216*.
- [2] CDF Collaboration, *CDF Conference Note 10394*.
- [3] A. Abulencia et al. (CDF Collaboration), *Phys. Rev. D* **74**, 071103(R) (2006).
- [4] T. Aaltonen et al. (CDF Collaboration), *Phys. Rev. Lett.* **100**, 102001 (2008).
- [5] T. Aaltonen et al., *Phys. Rev. D.* **79**, 052008 (2009).
- [6] CDF Collaboration, *CDF Conference Note 10594*.