W/Z+Jets Results from CDF

Stefano Camarda

IFAE - Barcelona

On Behalf of CDF Collaboration

ICHEP
July 22-28, 2010
Paris
Motivation

- Test perturbative QCD at high $Q^2$
- Background for top measurements and new Physics searches
- 30% - 40% uncertainty in some of the processes (boson + HF)

CDF Run II Preliminary (4.1 fb⁻¹)

Single T Tag
- $M_H = 120$ GeV/$c^2 \times 150$ After NN Corr.
- $M_H = 120$ GeV/$c^2 \times 150$ Before NN Corr.

HIGGS search
- $Z + t\bar{t}$
- $Z + c\bar{c}$
- $t\bar{t}$
- Fakes

SUSY search squarks
- Mis.
- QCD
- Top
- Wjet
- Zjet
- Di-boson

Top – Lepton + jets
- 1 Jet
- 2 Jets
- 3 Jets
- 4 Jets
- ≥5 Jets

Events

Number of Events

Stefano Camarda
Latest W/Z + jets results from CDF

- $Z \rightarrow \mu^+\mu^- + \text{jets}$ production cross section
- $W + \text{charm}$ production cross section
- $Z + \text{jet } P_T$-balance

New results with 4 to 6 fb$^{-1}$

Previous results
- $Z \rightarrow ee + \text{jets}$
  - PRD 100, 102001 (2008)
- $W \rightarrow ev + \text{jets}$
  - PRD 77, 011108(R) (2008)
- $Z + b$
  - PRD 79, 052008 (2009)
- $W + b$
  - PRL 104, 131801 (2010)
Tevatron and CDF

- $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV
- Peak instantaneous luminosity
  $\sim 4 \times 10^{32}$ cm$^{-2}$ s$^{-1}$
- 7.5 fb$^{-1}$ of integrated luminosity on tape
CDF Detector

- Tracking system
  - Silicon detectors
  - Drift chambers COT
- 1.4 T Magnetic field
- Calorimeter
  - Electromagnetic calorimeter
  - Hadronic calorimeter
- Muon detectors
  - Wire chambers
  - Scintillators
- 3 Level Trigger System
  - Level 3 → ~ 100 Hz
\[ \text{Z/}\gamma^* \rightarrow \mu^+\mu^- + \text{jets} \]

**Kinematic region**

**Muons**
- \( P_T > 25 \text{ GeV/c} \)
- \( |\eta| < 1.0 \)
- \( 66 < M_{\mu\mu} < 116 \text{ GeV/c}^2 \)

**Jets Midpoint \( R = 0.7 \)**
- \( P_T > 30 \text{ GeV/c} \)
- \( |Y| < 2.1 \)

- *Important background for ZH → ll bb, SUSY MET + jets*
- *Test pQCD NLO predictions*

Measurements are unfolded back to Hadron level
Background estimation

Data driven backgrounds
(Same Charge tracks)
- QCD dijet
- W + jet
- \( \mu \) fakes

MC backgrounds
- \( Z + \gamma \)
- Top
- Diboson
- \( Z \rightarrow \tau \tau \)

- \( \sim 13000 \) \( Z + \geq 1 \) jet data events in 6 fb-1
- Total backgrounds between 5%-10%
- Main background is \( Z+\gamma \)
Systematic uncertainties

5% to 15% systematic uncertainties
Jet Energy Scale is the dominant

- Jet Energy Scale 3 – 15%
- Data driven backgrounds 1 – 8%
- Monte Carlo backgrounds 1 – 3%
- Trigger and Muon ID efficiencies < 1%
- Multiple pp interaction 1 – 6%
- Primary Vertex acceptance < 1%
\(Z/\gamma^* \rightarrow \mu^+ \mu^- + \geq 1 \text{ jet}\)

Good agreement with NLO prediction (MCFM) corrected for non-pQCD effects.
$Z/\gamma^* \rightarrow \mu^+\mu^- + \geq 2 \text{ jet}$

Good agreement with NLO prediction (MCFM) corrected for non-pQCD effects
\[ Z/\gamma^* \rightarrow \mu^+\mu^- + \geq N \text{ jets} \]

Good agreement between data and NLO prediction in \( \geq 1 \) jet and \( \geq 2 \) jets bins.

Data suggest a ratio to LO of \( \sim 1.4 \)

- \( \sim 130 \) events in \( \geq 3 \) jets bin
- 10 events of \( Z^+ \geq 4 \) jets
**$Z/\gamma^* \rightarrow e^+e^- + \text{jets}$**

- Measurement on the $e^+e^-$ channel Published in PRL 100, 102001 (2008) with 1.7 fb$^{-1}$

- Updated measurement with 2.5 fb$^{-1}$

**Plan to combine muons and electrons channels**

CDF Run II Preliminary

- CDF Data $L = 2.5$ fb$^{-1}$
- Systematic uncertainties
- NLO MCFM CTEQ6.1M corrected to hadron level $\mu_0^2 = M_Z^2 + p_T^2(Z)$, $R_{pdf} = 1.3$
  - $\mu = 2\mu_0$; $\mu = \mu_0/2$
- PDF uncertainties

- $d\sigma/dp_T^{\text{jet}}$ [fb/(GeV/c)]

<table>
<thead>
<tr>
<th>Jet Inclusive</th>
<th>Data / Theory</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30</td>
</tr>
<tr>
<td>2</td>
<td>100</td>
</tr>
<tr>
<td>3</td>
<td>200</td>
</tr>
</tbody>
</table>

- Ratio to LO

- $N_{jets} \geq N_{jets}$
W + single c Production

- Probe s-content of proton at high $Q^2$
  - $g+s \sim 90\%$ $g+d \sim 10\%$
- Background for single-top, $W + H$

**Event Selection**

- $W \rightarrow l \nu$ selected by high $p_T$ $e, \mu +$ MET
- JETCLU $R = 0.4$ jet with $E_T > 20$ GeV/c and $|\eta| < 2.0$
- Charm-jet identified by soft electron tagging (SLT$_e$) algorithm
- Exploit opposite charge correlation between $W$ lepton and SLT electron

\[
\sigma_{W+c} \times Br(W \rightarrow l \nu) = \frac{N_{OS-SS}^{data} - N_{bkg}^{OS-SS}}{\epsilon \cdot A \cdot L}
\]

New results based on 4.3 fb$^{-1}$
W + charm background

QCD background is estimated by a fit to the MET spectrum

Main backgrounds:
- Fake W (QCD)
- W + light jets
- Drell-Yan

Background validation in OS+SS control region
Stefano Camarda

W + charm result

Soft electron tagger validation

Main systematic uncertainties:
- $Q^2$ 10%
- SLT tagging efficiency 8.8%
- Luminosity 8.3%
- PDF 8%
- ISR/FSR 7%
- Jet Energy Scale 6%

Charm $p_T > 20$ GeV/c and $|\eta| < 1.5$

$$\sigma_{W+c} \times Br(W \rightarrow l \nu) = 21.1 \pm 7.1 \text{ (stat)} \pm 4.6 \text{ (syst)} \text{ pb}$$

$NLO$ prediction ($MCFM$): $11.0^{+1.4}_{-3.0}$ pb

Data and NLO in reasonable agreement
**W + charm − μ channel**

Previous result with 1.8 fb$^{-1}$ in the charm → μ channel

Soft muon tagger validation

Charm $p_T > 20$ GeV/c and $|\eta| < 1.5$

$$\sigma_{W+c} \times Br(W \rightarrow l \nu) = 9.8 \pm 2.8 (stat)_{-1.6}^{+1.4} (syst) \pm 0.6 (lum) \text{ pb}$$

**NLO prediction (MCFM):** $11.0_{-3.0}^{+1.4} \text{ pb}$
W + b-jets

Both e and \( \mu \) channel

- \( P_T > 20 \text{ GeV/c} \)
- \(|\eta| < 1.1\)
- \( \text{MET} > 25 \text{ GeV} \)

One or two jets (JETCLU R=0.4)

- \( E_T > 20 \text{ GeV} \)
- \(|\eta| < 2.0\)

\[ \sigma_{W+b} \times Br \left( W \to l \nu \right) = 2.74 \pm 0.27 \pm 0.42 \text{ pb} \]

\( b \)-quark composition extracted from fit to secondary vertex mass

Result with 1.9 fb\(^{-1}\)

Measured Xs is higher than NLO prediction

\( \text{ALPGENv2 + PYTHIA 6.3} = 0.78 \text{ pb} \)

\( \text{NLO } pQCD = 1.22 \pm 0.14 \text{ pb} \)
Z + b-jets

Both e and μ channel, jets with $E_T > 20$ GeV and $|\eta| < 1.5$ (JETCLU R = 0.7)

\[
b\text{-quark composition extracted from fit to secondary vertex mass}
\]

\[
\begin{align*}
\frac{\sigma_{Z+b-jet}}{\sigma_Z} &= 3.32 \pm 0.53 \pm 0.42 \times 10^{-3} \\
\text{MCFM: } 2.3 \times 10^{-3} (Q^2 = M_Z^2 + P_{T,Z}^2) \\
2.8 \times 10^{-3} (Q^2 = \langle P_{T,Jet}^2 \rangle)
\end{align*}
\]

Measurement in agreement with NLO prediction (large uncertainties in both data and theory)
**Z+jet $P_T$ balance**

- Reduce uncertainties on measured energy of hadronic jets
- Test QCD jet modeling
- Check quark-gluon composition

New study based on 4.6 fb$^{-1}$

$P_T$-balance definition

$$\langle P_T(jet1)/P_T(Z) \rangle$$

**Out-of-cone radiation**

Mismodeling of large angle FSR in the MC is limiting the uncertainty in hadronic jets energy

Stefano Camarda
Summary

• New results on $Z + \text{jets}$ in good agreement with NLO predictions

• $W + \text{single charm}$ in reasonable agreement

• $Z + \text{jet } P_T$ balance open new possibilities to improve jet energy measurement

→ $Z + \text{jets}$ prospects for 6 fb$^{-1}$ $e/\mu$ channels combination
→ $Z/W + \text{HF}$ need more data and better predictions