W/Z + jets measurements at DØ

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On behalf of the DØ Collaboration
Vector Boson + Jets ($N_{\text{jet}} = 1, 2, 3 ...$)

- relevant to other high-multiplicity processes
- background to Higgs

Provide detailed measurements of $p_T$ and angular distributions of vector boson and jet
→ test perturbative QCD calculations
→ testing and tuning of phenomenological models
Differential $Z/\gamma^* \rightarrow \mu^+ \mu^-$ cross section, D0

$65 < M_{\mu\mu} < 115$ GeV, $|y_\mu| < 1.7$, $p_T^{\text{jet}} (R=0.5) > 20$ GeV, $|y_{\text{jet}}| < 2.8$

Pt- jet dependence

Jet- rapidity dependence

NLO pQCD: MCFM v5.4
PDF: CTEQ6.6M
$\mu_r^2 = \mu_f^2 = M_Z^2 + p_T^2, Z$

PYTHIA 6.323,
ALPGEN 2.05,
SHERPA 1.1.1,
PDF: CTEQ6.1M

NLO pQCD prediction
5% below measured cross section.
For $p_T(Z) < 30$ GeV prediction sensitive to underlying event
Total cross section prediction of ALPGEN and PYTHIA significantly below data
Differential $Z/\gamma^* + 1\text{jet} + X$ cross section, $D0$

$$\sigma(z/\gamma^*(\rightarrow\mu\mu) + \text{jet} + X) = 18.7 \pm 0.2(\text{stat.}) \pm 0.8(\text{syst.}) \pm 0.9(\text{muon}) \pm 1.1(\text{lumi.}) \text{ pb}$$

1. The shapes are well described by NLOpQCD
2. Cross section at lower $Pt-Z$ is dominated by non-perturbative process.
Differential $Z/\gamma^*(\rightarrow \mu^+\mu^-)$ + jets: angular correlations

- Normalized diff. cross section in $\Delta\phi(Z, \text{leading jet})$, $p_T^Z > 25$ GeV

SHERPA is preferred by data
Differential $Z/\gamma^* (\rightarrow \mu^+\mu^-) + \text{jets}$: rapidity correlations

- Normalized diff. cross section in $\Delta y(Z, \text{leading jet})$, $p_T^Z > 25$ GeV

- NLO pQCD is preferred by data
Measurement of 1st, 2nd and 3rd jet $p_T$ in $Z$ events:

- normalize to inclusive $Z$ production (cancel some uncertainties)
- compare to pQCD @ LO / NLO

Cross Section for $Z/\gamma +$ jets $\,(1,2,3)$ + $X$, D0
Ratios of data and different MC generators $\rightarrow$ favor ALPGEN + PYTHIA w/ low scale
For “ALPGEN + PYTHA” (---) scales (factoriz. and renorm.) can be chosen so that a good, simultaneous agreement with data is achieved for all three leading jets.

**Leading jet in Z + jet + X**

**Second jet in Z + 2jet + X**

**Third jet in Z + 3jet + X**
\[ \frac{\sigma(Z+b)}{\sigma(Z+\text{jet})} \text{ ratio measurement} \]

- **Event Selection**
  - Dilepton mass \(70 \leq M \leq 110\) GeV
  - \(\geq 1\) jet: \(p_T > 20\) GeV, \(|\eta|<1.1\)

- **Inputs for NN tagging algorithm**
  - Decay length significance of sec. vtx
  - No. of tracks associated to sec. vtx.
  - Mass of the sec. vertex
  - (reduced) Jet Lifetime Probability, rJLIP: confidence level that all tracks in a jet originate from primary vertex
  - etc., 9 in total

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**Before tagging**

![Graph showing event selection criteria](image)

**D0 Run II Preliminary**

- **Data**
- **Z + l**
- **Z + b**
- **Z + c**
- **t\bar{t}bar**
- **Diboson**
- **Multijet**

![Diagram of displaced tracks](image)
Separation of light, c and b jets

- Apply Neural Network tagging algorithm on jets to enrich b content
- Use rJLIP variable to discriminate between light, c and b jets
- Light jet template is derived from “Negatively Tagged” (NT) data
  - Jets are formed from tracks that have negative values for some of the inputs for the NN algorithm
- Use Alpgen+Pythia for b and c jet templates
- Use log likelihood fit to extract Z+b fraction from the preselected sample
Ratio of Cross Sections $Z + b$-jet/$Z + \text{jet}$, D0

$\sigma(Z+b)/\sigma(Z+\text{jet})$: preliminary results

<table>
<thead>
<tr>
<th>Fraction</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Z+b$ fraction</td>
<td>$0.191 \pm 0.030$</td>
</tr>
<tr>
<td>$Z+c$ fraction</td>
<td>$0.384 \pm 0.072$</td>
</tr>
<tr>
<td>$Z+$ light jet fraction</td>
<td>$0.424 \pm 0.054$</td>
</tr>
<tr>
<td>$\sigma(Z+b)/\sigma(Z+\text{jet})$ NLO/MCFM</td>
<td>$0.0176 \pm 0.0024 \text{ (stat)} \pm 0.0023 \text{ (syst)}$</td>
</tr>
<tr>
<td></td>
<td>$0.0184 \pm 0.0022$</td>
</tr>
</tbody>
</table>
Ratio of Cross Sections $Z + b$-jet/$Z+$jet, D0

$$\sigma (Z + b$-jet) / \sigma (Z + jet) = 0.021 \pm 0.005$$

L = 180 pb$^{-1}$

$$\sigma (Z + b$-jet) / \sigma (Z + jet) = 0.0208 \pm 0.0033\text{(stat.)} \pm 0.0034\text{(syst.)}$$

L = 2.0 fb$^{-1}$

$\sigma(Z+b)/\sigma(Z+\text{jet})$

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<th>NLO/MCFM</th>
<th>0.0176 ± 0.0024 (stat) ± 0.0023 (syst)</th>
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Ratio of the $W+c$-jet+$X$ Cross Section to the $W+\text{jets}+X$ Cross Section, D0

Relative transverse momentum of the jet-muon with respect to the jet axis, $p_T^{\text{rel}}$, shows the consistency between data and the $c$-jet expectation.

Ratio is close to the prediction of Alpgen + PYTHIA.
The measured $W + c$-jet fractions integrated over $p_T > 20$ GeV and $|\eta| < 2.5$ are

$$\frac{\sigma [W (\rightarrow e\nu) + c\text{-jet}]}{\sigma [W (\rightarrow e\nu) + \text{jets}]} = 0.073 \pm 0.023(\text{stat.})^{+0.012}_{-0.014}(\text{syst.}),$$

$$\frac{\sigma [W (\rightarrow \mu\nu) + c\text{-jet}]}{\sigma [W (\rightarrow \mu\nu) + \text{jets}]} = 0.075 \pm 0.031(\text{stat.})^{+0.015}_{-0.017}(\text{syst.}).$$

Since the $W \rightarrow e\nu$ and $W \rightarrow \mu\nu$ measurements are consistent with one another, and statistical uncertainties dominate, the two lepton channels are combined to yield

$$\frac{\sigma [W + c\text{-jet}]}{\sigma [W + \text{jets}]} = 0.074 \pm 0.019(\text{stat.})^{+0.012}_{-0.014}(\text{syst.}).$$
Isolated Photon + HF Jet

Photon + (b/c) jet + X
Photon $p_T$: 30-150 GeV

$0.01 < x < 0.3 \rightarrow b, c, \text{gluon PDF}$
$\rightarrow \text{test gluon splitting contribution}$

tag photon and jet

Rapidities:

$$|y^\gamma| < 1.0 \quad |y^{\text{jet}}| < 0.8$$

$\rightarrow \text{triple differential}$

$$\frac{d^3 \sigma}{(dp_T^\gamma dy^\gamma dy^{\text{jet}})}$$
W+jets production

- The measurement tests $W+n$-jet ($n=1-4$) production cross section vs $n$-th jet $p_T$
- Normalized to $\sigma(W)$
- Comparison to LO&NLO by Blackhat+Sherpa and Rocket+MCFM


Theor. scale uncertainty
W+jets production D0

Dominant background to the single top, ttbar, SM Higgs, many BSM searches

- The measurement tests W+n-jet (n=1-4) production cross section vs n-th jet pT
- Comparison to LO&NLO by Blackhat+Sherpa and Rocket+MCFM (different scales)

In agreement with QCD NLO in jet pT and #jets
Experimental uncertainties are lower than theoretical (scale) in many cases
=> tuning the theory
First W+4jets result (only LO prediction has been available for the Tevatron)
– W+n-jet differential x-section in ~40(!)variables is in a review
Ratio of Cross Sections Z + b-jet/Z+jet , D0

L = 4.2 fb^{-1}

D0 Note 6053--CONF (2010)

σ(Z+b)/σ(Z+jet) ratio measurement

• Event Selection
  • Dilepton mass 70 ≤ M ≤ 110 GeV
  • ≥ 1 jet: p_T > 20 GeV, |η| < 1.1

Before tagging

• Inputs for NN tagging algorithm
  – Decay length significance of sec. vtx
  – No. of tracks associated to sec. vtx.
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    in a jet originate from primary vertex
  – etc., 9 in total
x-section ratio \((Z+b)/ (Z+\text{jet})\)

- Important background to the SM Higgs search in the ZH channel.
- Probe of b-quark PDF, important for \(gb \rightarrow Hb\) & single-top studies
- Measurement of x-section ratio \((Z+b)/(Z+j)\) benefits from cancellation of many systematics => precise comparison with theory

- Measurement: \(0.0193 \pm 0.0022\) \text{(stat)} \(- 0.0015\) \text{(syst)} \([\sim 8\% \text{ syst}]\)
  Most precise measurement of 'Z+b' fraction to date!
- Consistent with NLO theory: \(0.0192 +/- 0.0022\)
  (MCFM, renorm. and factor. scales are at \(MZ\))
- Differential measurement in b-jet \(p_T\), \((Z,\text{jet})\) angles in progress
Many new, interesting results are coming from the Tevatron in Vector Boson + jet measurements.

=> Crucial for understanding backgrounds to NP and SM Higgs searches.

- Some discrepancies with theory suggest HO corrections and some theory components may need study: tuning of scale choices, PDFs, heavy quark fragmentation, etc.

- Understanding of W+b jet x-section is extremely important.
- New results on W+n-jets, Z+b and W+b are coming soon.
- Be tuned by looking at

**D0:** http://www-d0.fnal.gov/Run2Physics/qcd/D0_public_QCD.html

**CDF:** http://www-cdf.fnal.gov/physics/new/qcd/QCD.html
Backup