Study of $W+\gamma$ Production at the Tevatron

Ai Nagano
University of Tsukuba
for CDF collaboration
DPF 2006

Outline
- Introduction
- Event Selection
- $W$ cross section result
- $W + \gamma$ cross section
- Conclusion
Introduction

- measure $W^+ \gamma$ cross section
- The $W^+ \gamma$ kinematic distribution is sensitive to anomalous couplings
- Search for physics beyond standard model
  - excess in high photon $E_T$
  - excess in large $\Delta R(l, \gamma)$
- ISR and s-channel interfere each other. Radiation amplitude zero

The initial state radiation from an incoming quark

- Photon is radiated from $W$ boson. Interesting triple gauge coupling
- The final state radiation. Photon is radiated from Bremsstrahlung process
W Event Selection

- High $p_T$ muon Datasets 1/fb
- W Event Selection
  - one isolated high $p_T$ muon: $p_T > 20$ GeV
  - neutrino observed as missing transverse energy: MET > 20 GeV
  - $30 \text{ GeV} < M_T(W) < 120$ GeV
  - Supress $Z \rightarrow \mu\mu$: no isolated track $p_T > 10$ GeV
  - Cosmic Ray veto

Background
- QCD background (0.87 %)
  - determined from Data
- $Z \rightarrow \mu\mu$ background (7.74 %)
  - determined from PYTHIA Monte Carlo
- $W \rightarrow \tau\nu$ background (3.04 %)
  - determined from PYTHIA Monte Carlo

The plane is divided into four region assuming no correlation between Isolation and MET. Region D is signal region.

\[
\frac{\text{# of events in A}}{\text{# in B}} \times \text{(# in C)}
\]
W cross section in Muon Channel as a cross check

- We observed 520818 W candidates in muon channel.
- \( \sigma (W \rightarrow \mu \nu) = 2.78^{+0.01}_{-0.01} \text{(stat.)}[\text{nb}] \)
- agree well with published result 72/pb PRL 94, 091803
  - 2.775^{+0.01}_{-0.01}(\text{stat.})^{+0.053}_{-0.01}(\text{sys.})^{+0.167}_{-0.1}(\text{lum.}) \text{ [nb]}
- Thus we can move on to W+\gamma analysis
W kinematic distributions

Data agree with Standard model prediction
W+γ Event Selection in Muon Channel

- After inclusive W selection then add photon selection.
- W+γ process
  - simulated by Monte Carlo program by U. Baur
  - It contains initial and final state photon radiation and the trilinear gauge coupling process.
- Photon ID
  - E_T > 7 GeV
  - |η| < 1.0
- W+γ Selection
  - ΔR (lepton,photon) > 0.7
W+\gamma Background contributions

- **W+jet** is the largest background, 22.7%
  - Jet misidentified as photon
  - Determined from data
  - Measure the photon fakerates versus jet $E_T$

- **Z+\gamma \rightarrow \mu\mu\gamma** 13.1%
  - One muon not identified
  - Determined from Monte Carlo

- **W+\gamma \rightarrow \tau\nu\gamma** 1.5%
  - Determined from Monte Carlo

0.3% at photon $E_T=7\text{GeV}$
0.03% at photon $E_T>50\text{GeV}$
The $W+\gamma$ cross section in the kinematic range of $\Delta R(\mu,\gamma) > 0.7$ and photon $E_T > 7$ GeV using photon $|\eta| < 1.0$

<table>
<thead>
<tr>
<th></th>
<th>Number of Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>$W\gamma$</td>
<td>$541.7 \pm 4.02 \text{(stat.)} \pm 1.57 \text{(sys.)}$</td>
</tr>
<tr>
<td>$W$+jet</td>
<td>$194.3 \pm 0.15 \text{(stat.)} \pm 66.91 \text{(sys.)}$</td>
</tr>
<tr>
<td>$Z\gamma$</td>
<td>$112.0 \pm 0.39 \text{(stat.)} \pm 0.32 \text{(sys.)}$</td>
</tr>
<tr>
<td>$W\gamma(\tau)$</td>
<td>$12.4 \pm 0.60 \text{(stat.)} \pm 0.04 \text{(sys.)}$</td>
</tr>
<tr>
<td>Number of Total</td>
<td>$860.4 \pm 29.25 \text{(stat.)} \pm 66.95 \text{(sys.)}$</td>
</tr>
</tbody>
</table>

Number of Observed: 855

$\sigma (W\gamma \rightarrow \mu \nu \gamma) = 19.11 \pm 1.04 \text{(stat.)} \pm 2.40 \text{(sys.)} \pm 1.11 \text{(lumi.)} \text{[pb]}$

theoretical NLO cross section: 19.3$\pm$1.4 pb
The photon fake rate uncertainty yields the dominant uncertainty on the cross section.

<table>
<thead>
<tr>
<th>Source</th>
<th>% effect on $\sigma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luminosity</td>
<td>5.8</td>
</tr>
<tr>
<td>Jet Fake</td>
<td>10.1</td>
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<tr>
<td>Trigger Efficiency</td>
<td>0.5</td>
</tr>
<tr>
<td>Tracking Efficiency</td>
<td>0.2</td>
</tr>
<tr>
<td>Muon ID</td>
<td>0.6</td>
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<tr>
<td>Muon Momentum Scale</td>
<td>0.2</td>
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<tr>
<td>Photon Energy scale</td>
<td>1.0</td>
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<tr>
<td>Photon ID</td>
<td>3.0</td>
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<tr>
<td>Z vertex cut efficiency</td>
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<tr>
<td>Cosmic rejection</td>
<td>0.01</td>
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<tr>
<td>Conversion</td>
<td>2.0</td>
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<tr>
<td>Acceptance</td>
<td>3.0</td>
</tr>
<tr>
<td>Total (excluding Luminosity)</td>
<td>12.6</td>
</tr>
</tbody>
</table>
Data agree well with Standard Model prediction
Study of $W+\gamma$ Production at the Tevatron

Transverse Mass $(\mu, \nu)$ vs Cluster $M_T(\mu \gamma, \nu)$

- ISR, s-channel Event
  - Invariant Mass$(\mu, \nu) = M_W$
  - Cluster $M_T(\mu \gamma, \nu) > M_W$

- FSR Event
  - Invariant Mass$(\mu, \nu) < M_W$
  - Cluster $M_T(\mu \gamma, \nu) \sim M_W$

Cluster $M_T(\mu \gamma, \nu) = 90$

In future plan, we can separate ISR, s-channel Events from FSR with cluster $M_T(\mu \gamma, \nu) > 90$ GeV cut.
Mass distributions

CDF RunII Preliminary 1/fb

- Data 855 events
  - $W+\gamma \rightarrow \mu\nu\gamma$
  - $W+\text{jet}$
  - $Z+\gamma$
  - $W+\gamma \rightarrow \tau\nu\gamma$

Number of Events/(10GeV/c^2)

Transverse Mass($\mu$, $\nu$) (GeV/c^2)

Cluster Transverse Mass($\mu\gamma$, $\nu$) (GeV/c^2)
W$+\gamma$ Candidate Event Display

- Photon $E_T = 159$ GeV
- Muon $p_T = 121.6$ GeV/c
- MET = 24.4 GeV

<table>
<thead>
<tr>
<th>photon $E_T$</th>
<th>muon $p_T$</th>
<th>MET</th>
<th>$M_T$</th>
<th>cluster $M_T$</th>
<th>$\Delta R$</th>
</tr>
</thead>
<tbody>
<tr>
<td>159.</td>
<td>121.6</td>
<td>24.4</td>
<td>63.9</td>
<td>304.</td>
<td>2.76</td>
</tr>
</tbody>
</table>
Conclusion

- W+γ cross section measured in 1/fb
  - $\sigma \text{ BR}(W \rightarrow \mu \nu) = 19.11\pm1.04$ (stat.) $\pm 2.40$ (sys.) $\pm 1.11$ (lumi.) [pb]
  - theoretical NLO cross section 19.3$\pm1.4$ pb

- very good agreement with standard model prediction.

- Plan
  - extract anomalous couplings
  - study radiation amplitude zero