W,Z + jets studies at Tevatron relevant to Higgs searches at LHC

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TEV4LHC, Higgs Session 09/16/04
Outline

Introduction
- \( H+\)jets in Higgs searches at the LHC
- Considerations on background extraction

\( W,Z+\)jet studies for \( H+2\)jets (VBF)

\( Z+1\)jet studies for \( \tau\tau+\)jet final state

Jet veto studies for \( pp\rightarrow WW+X\)

Outlook
Low Mass SM Higgs Potential at LHC

Working Plots, not ATLAS official

LEP Limit

$H \rightarrow WW^{(*)} + 0, 1, 2 \text{ jets}$

$H \rightarrow ZZ^{(*)}$

$H \rightarrow \tau\tau + 1, 2 \text{ jets}$

$H \rightarrow \gamma\gamma + 0, 1, 2 \text{ jets}$

$t\bar{t}H(\rightarrow bb)$

$\int L \, dt = 10 \, \text{fb}^{-1}$

Bruce Mellado, Higgs Session TEV4LHC 09/16/04
H+jets in Low Mass Higgs Searches at the LHC

H+jets will play a very important role at the LHC in observing a low mass Higgs

- These analyses are harder than purely inclusive ones

Relative Sensitivity of H+jets (preliminary)

<table>
<thead>
<tr>
<th>H→ττ</th>
<th>H→γγ</th>
<th>H→WW(*)</th>
<th>H→ZZ(*)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100%</td>
<td>~50%</td>
<td>~50%</td>
<td>~0% (?)</td>
</tr>
</tbody>
</table>

Together with ttH(→bb) most important final states close to LEP limit (114 GeV)
On background extraction

The determination of the SM (mostly QCD) backgrounds associated with jets will rely on LHC data itself

- Will not rely on a prediction based on extrapolation from Tevatron to LHC

Control samples in Data are well defined

- Will require a certain degree of extrapolation from control sample phase space to signal-like region
- If MC are used for this, extrapolation needs to be validated with Data
- Tevatron plays a central role in validating MC tools, which will be extensively used at the LHC
On background extraction (cont)

Take example of $H(\rightarrow \tau \tau) + \text{Jets}$: Main background $Z+\text{jets}$

- Can be generalized to rest of final states

Control Sample 1
$Z \rightarrow e e, \mu \mu$
Loose cuts on Jets

Control Sample 2
$Z \rightarrow \tau \tau$
Loose cuts on Jets

Control Sample 3
$Z \rightarrow e e, \mu \mu$
Tight cuts on Jets

Replace $Z \rightarrow e e, \mu \mu$ by $Z \rightarrow \tau \tau$

MC extrap. is validated

Signal Region
$Z \rightarrow \tau \tau$
Tight cuts on Jets

Determine shape of $Z \rightarrow \tau \tau$ background
Normalization taken from Data in signal-like region
H+2jets (VBF) at the LHC

D. Zeppenfeld, D. Rainwater, et al. proposed to search for a Low Mass Higgs in association with two jets

Jet

Jet

Tagging Jets

Central Jet Veto

Higgs Decay Products

\[ \eta_{J1} \cdot \eta_{J2} < 0 \]
\[ \Delta \eta_{JJ} > 3.5 \div 4 \]
\[ M_{JJ} > 500 \div 700 \text{GeV} \]
c.j.v.
H+2jets (VBF) at the LHC (cont)

Study additional (central) jet production to $W + 2$ forward and separated jets (tagging jets)

- Cross-section dependence on separation in pseudorapidity between tagging jets
- Rate of third jet
- Angular correlations between tagging jets and central jet

- Comparison with QCD predictions
  - Test interplay between perturbative and parton shower approaches
H+2jets (VBF) at the LHC (cont)

Effective cross-sections (in pb) evaluated with MadGraphII for the Tevatron

- Fast simulation with basic detector response (thanks to M. Martinez and Y-K. Kim)

<table>
<thead>
<tr>
<th>Process</th>
<th>$\eta_{j_1,j_2} &gt; 2$</th>
<th>$\eta_{j_1,j_2} &gt; 2.5$</th>
<th>$\eta_{j_1,j_2} &gt; 3$</th>
<th>$\eta_{j_1,j_2} &gt; 3.5$</th>
<th>$\eta_{j_1,j_2} &gt; 4$</th>
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</thead>
<tbody>
<tr>
<td>QCD $Wjj$</td>
<td>7.07</td>
<td>4.29</td>
<td>2.40</td>
<td>1.23</td>
<td>0.56</td>
</tr>
<tr>
<td>EW $Wjj$</td>
<td>0.12</td>
<td>0.07</td>
<td>0.04</td>
<td>0.03</td>
<td>0.01</td>
</tr>
<tr>
<td>QCD $Wjjjj$</td>
<td>0.34</td>
<td>0.22</td>
<td>0.13</td>
<td>0.07</td>
<td>0.04</td>
</tr>
</tbody>
</table>

$W+2j$ and $W+4j$ display large enough cross-section at the Tevatron

- Very hard to disentangle EW from QCD $W/Z$ production
$H(\rightarrow \tau\tau)+1\text{jet at the LHC}$

Tag one semi-central jet, require $P_{TH}>100$ and $M_{HJ}>700$ GeV and a loose central jet veto ("top killer")

- Allow significant contribution from $gg\rightarrow h$

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hep-ph/0406095
submitted to PL

Higgs Decay Products
$P_{TH}>100$ GeV

Loose Central Jet Veto
("top killer")

Quasi-central Tagging Jet
QCD $Z+1j$ production gives about 50% of background

- Need to evaluate role of QCD higher order corrections
  - These are not trivial due to specifics of cuts
QCD HO Corrections in QCD $Z+1\text{jet}$

\[ \sigma(x_\mu) \text{ (pb)} \]

\[ \mu_R = \mu_F = x_\mu M_Z \]

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K Factor

Moderate K factor of about 1.2 for inclusive Z+1j production

\[ \mu_R = \mu_F = x_\mu M_Z \]
QCD HO Corrections in QCD Z+1jet (Kinematic Effects)

**MC@NLO:** Kinematic effects of Higher Order corrections to Z+1j (incorporates LO Z+1j ME) are given by Parton Showers

- Certain limitations, which are analysis dependent

**SHERPA** incorporates consistent matching between multi-parton tree-level ME with Parton showers

- It gives rates to LO but it is a good tool to address kinematic effects of extra hard gluon radiation in the final state

- Generate same number of events with Z+1j ME + PS and Z+2j ME + PS with SHERPA
Z+1jet Study with SHERPA

Z+1j ME

Parton Shower for extra gluon radiation

Z+2j ME

Parton Shower for extra gluon radiation
Require at least one jet with $P_T > 30$ GeV

To define an extra jet $P_T > 30$ GeV is also required

$N_{cj} = \text{number of extra jets with } |\eta| < 2$
Strong effect on $P_T$ of leading jet and the invariant mass of Z and the leading jet
Central jet veto ("top killer", $p_{TJ}<30\text{GeV}$) significantly reduces effect of higher order corrections

- With $M_{ZJ}>700\ \text{GeV}$ $Z+1j$ increases by factor of 2
Enhancement of $Z+1j$ background due to extra gluon radiation may be excellent news to the analysis.

$H+1j$ and $Z+1j$ diagrams bear strong similarities. Expect similar effect on Higgs production.

- If signal enhancement turns out to be large then it would be a good idea to remove the central jet veto to further improve the signal significance.
- Requires study within SHERPA.
Require at least one jet with $P_T > 20$ GeV
To define an extra jet $P_T > 20$ GeV is also required

- $N_{cj} =$ number of extra jets with $|\eta| < 2$
Cross-section is large enough at the Tevatron to do studies at large $P_{TZ}$, $P_{TJ}$ and $M_{ZJ}$

- About 100-200 fb for $P_{TZ} > 100$ GeV
**W/Z + jets in CDF**

Preliminary, (kindly provided by CDF)

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**W+jets**

*central electrons*

<table>
<thead>
<tr>
<th>( n )</th>
<th>( \geq 0 )</th>
<th>( \geq 1 )</th>
<th>( \geq 2 )</th>
<th>( \geq 3 )</th>
<th>( \geq 4 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( N_n )</td>
<td>54799</td>
<td>11615</td>
<td>2680</td>
<td>602</td>
<td>145</td>
</tr>
<tr>
<td>( B_n )</td>
<td>1869</td>
<td>951</td>
<td>349</td>
<td>138</td>
<td>55</td>
</tr>
</tbody>
</table>

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**Z+jets**

*central electrons*

<table>
<thead>
<tr>
<th>( \geq 0 )</th>
<th>( \geq 1 )</th>
<th>( \geq 2 )</th>
<th>( \geq 3 )</th>
<th>( \geq 4 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( N_{n,\text{cand}} )</td>
<td>4232</td>
<td>935</td>
<td>193</td>
<td>40</td>
</tr>
<tr>
<td>( N_{n,bkg} )</td>
<td>6.51</td>
<td>8.01</td>
<td>3.82</td>
<td>0.67</td>
</tr>
<tr>
<td>( \epsilon_n (%) )</td>
<td>80.53</td>
<td>76.66</td>
<td>70.31</td>
<td>69.78</td>
</tr>
<tr>
<td>( A_n (%) )</td>
<td>10.81</td>
<td>10.13</td>
<td>9.40</td>
<td>9.48</td>
</tr>
</tbody>
</table>
Jet veto studies for $pp \rightarrow WW + X$

The application of a jet veto in $pp \rightarrow WW + X$ is fundamental to Low Mass Higgs searches with $H \rightarrow WW \rightarrow ll\nu\nu$ at the LHC.

MC will be validated with $tt, WW$ samples with $M_{ll} > M_H$, and $ZW$.

![Graph showing signal significance vs. $M_H$ (GeV)]

- $H+0j, H \rightarrow WW \rightarrow ll$
- $H+1j, H \rightarrow WW \rightarrow ll$
- $H+2j, H \rightarrow WW \rightarrow ll$
- Combined

$\int L \, dt = 10 \, fb^{-1}$

*Working Plots, not ATLAS official*
Different MC’s (Pythia and MC@NLO/Herwig) predict very different $P_T$ of $tt$ for LHC. Differences should be visible already at the Tevatron

$P_T$ of $tt$ strongly correlated to jet multiplicity
Outlook

Higgs associated with jets play a central role in searches for Low Mass Higgs at the LHC

- Need to extract reliably QCD backgrounds
  - Will rely on LHC data to extract QCD backgrounds

- Tevatron plays a central role in validating MC tools, which will be extensively used at the LHC

W/Z associated with jets are produced copiously enough at the Tevatron to study topologies relevant to $H+1j$ and $H+2j$ searches at the LHC

- Cross-sections for $W/Z+1,2,4$ jets are large enough to investigate relevant corners of the phase-space

Jet veto in $pp \rightarrow WW+X$ is central to Higgs searches with $H \rightarrow WW \rightarrow ll\nu\nu$ at the LHC