A Search For The Higgs Boson in the VBF $\text{H} \to \text{WW} \to 2l2\nu$ Mode with the CMS Detector

A. Benaglia$^{1,2}$ for the CMS Collaboration

$^1$Università degli Studi di Milano - Bicocca and INFN
$^2$École Polytechnique - LLR

29th July 2011

- Motivations for the VBF channel
- Description of the Higgs boson search in the $\text{WW} \to 2l2\nu$ mode:
- Results and exclusion limits with 1.1 fb$^{-1}$
- Conclusions
• The **Spontaneous Symmetry Breaking** (SSB) mechanism is essential to give mass to the weak bosons while preserving the fundamental gauge symmetry.

• The **VVH coupling** is (almost) sacred:
  - it is a **direct consequence of SSB**, while fermion masses arise indirectly through arbitrary Yukawa couplings
  - it **prevents** the WW scattering amplitude from **violating unitarity** at ~1 TeV

• The qqH, H→WW→2l2ν channel provides **direct access** to the **VVH coupling**
  - both on the **production** and on the **decay side**
The strategy to look for $H \rightarrow WW \rightarrow 2l2\nu$ events relies on:

- two energetic, isolated leptons (e or $\mu$) with $p_T > 20/10$ GeV/c
- large missing energy from undetectable neutrinos, i.e. $E^\text{miss}_T > 40 \,(20)$ GeV (S.F./O.F.)
- $Z$ veto: invariant mass of ee and $\mu\mu$ pairs must lay outside a $m_Z \pm 15$ GeV/c$^2$ mass window
- top veto: reject events with top-tagged jets
- $WZ/ZZ$ veto: reject events with a 3$^{\text{rd}}$ (4$^{\text{th}}$) good lepton candidate

Analysis is divided into 0, 1 and 2-jet bin

- count ParticleFlow anti-$k_T$ jets with $R=0.5$ that have $p_T > 30$ GeV/c and $|\eta| < 5$

more details in E. Di Marco’s talk

relevant for VBF
The VBF topology

• Despite $\sigma_{VBF}/\sigma_{gg-fusion} \approx 1/10$, the **VBF contribution** can be enhanced applying specific **topological selections**

• Exploit VBF process requiring **2 jets** *(tag jets)*:
  
  • no other hadronic activity between them *(in $\eta$)*
  
  • leptons lie within tag jets *(in $\eta$)*
  
  • $|\Delta \eta_{jj}| > 3.5$ and $m_{jj} > 450$ GeV/$c^2$
  
  • for $m_H < 200$ GeV/$c^2$, require that $m_{ll} < 100$ GeV/$c^2$

<table>
<thead>
<tr>
<th>mass</th>
<th>Higgs</th>
<th>WW</th>
<th>top</th>
<th>Zjets</th>
<th>Wjets</th>
<th>$\Sigma$ bkg</th>
<th>data</th>
</tr>
</thead>
<tbody>
<tr>
<td>140</td>
<td>$1.8\pm0.1$</td>
<td>0.5±0.2</td>
<td>2.0±1.2</td>
<td>0.6±0.6</td>
<td>0.5±0.4</td>
<td>3.6±1.4</td>
<td>3</td>
</tr>
<tr>
<td>160</td>
<td>$4.0\pm0.1$</td>
<td>0.5±0.2</td>
<td>2.0±1.2</td>
<td>0.6±0.6</td>
<td>0.5±0.4</td>
<td>3.6±1.4</td>
<td>3</td>
</tr>
<tr>
<td>200</td>
<td>$2.5\pm0.1$</td>
<td>0.5±0.2</td>
<td>2.0±1.2</td>
<td>0.6±0.6</td>
<td>0.5±0.4</td>
<td>3.6±1.4</td>
<td>3</td>
</tr>
<tr>
<td>400</td>
<td>$0.7\pm0.0$</td>
<td>0.6±0.2</td>
<td>2.8±1.6</td>
<td>0.6±0.6</td>
<td>0.4±0.4</td>
<td>4.5±1.8</td>
<td>4</td>
</tr>
</tbody>
</table>
Control of backgrounds

- Dominating background after full selection comes from **top events**:

  \[
  N_{\text{non\ tagged}}^{qqH} = \frac{N_{\text{tagged}}^{qqH} \times (1 - e_{\text{central\ jet}})}{e_{\text{central\ jet}}}
  \]

  number of events with the most central jet **top-tagged**

  top-tagging eff\(p_T, \eta\) for the most central jet measured in data

  a 10% correction factor is applied to account for most central jet outside tracker acceptance

- Second leading background comes from **DY events**:

  \[
  N_{\text{out}}^{\ell\ell, \text{exp}} = R_{\text{out/in}}^{\ell\ell} (N_{\text{in}}^{\ell\ell} - N_{\text{non-Z}}^{\text{in}} - N_{\text{ZV}}^{\text{in}})
  \]

  opposite-flavour VZ events measured in Z peak

  \(R_{\text{out/in}}^{\ell\ell}\) is measured in data and MC as well; systematics from its dependence on \(E_T^{\text{miss}}\) cut

  same-flavour events measured in Z peak

  same-flavour VZ contribution exp. from MC
**Systematic uncertainties**

- **Theoretical uncertainties on jet-bin fractions**
  - Compute $\sigma_{\geq 0\text{-jets}}$ (ggH) at NNLO, and $\sigma_{\geq 1\text{-jets}}/\sigma_{\geq 1\text{-jets}}$ (ggH+1/2 jets) at NLO with MCFM.
  - Syst. from $\mu_R(\mu_F)$ variation between $m_H/4$ and $m_H$.

- **Theoretical uncertainties on VBF predictions**
  - Vary $t/2 < \mu_R(\mu_F) < 2t$ and $\alpha_s$.
  - Repeat the procedure for loose/tight VBF cuts.

- **Experimental uncertainties on background estimation**
  - Top: 25%
  - Drell-Yan: 60%
**Cut based analysis**

- Simply **count number of events** after full selection is applied.
- **Drell-Yan**, **top** and **W+jets** backgrounds are evaluated from **data-driven** techniques at the end of the analysis.
- **Other backgrounds** are taken from **Monte Carlo** directly (WZ, ZZ, W+γ).

![Graphs showing tag jet η separation and tag jet invariant mass](image-url)
Results with 1.1 fb$^{-1}$

- Exclusion limit obtained with the CL$_{s}$-LHC method
- Observed limit is in very good agreement with SM expectations
- The **VBF channel alone** is sensitive to $\leq 2\times \sigma_{SM}$ in the range [150-200] GeV/c$^2$
Conclusions

- CMS searched for the **VBF-produced SM Higgs** in WW fully leptonic final state with 1.1 fb$^{-1}$ of data collected in 2011

- results in good agreement with SM expectations - no visible excess found

- **Results** for this production channel have been **combined with the 0 and 1-jet bins** (mostly gluon-fusion)

- With more data, and if a SM Higgs exists, this channel will allow to probe the electroweak nature of the **VVH coupling**
Backup