WH (H → b¯b) and VH Resonances
IOP 2015

Paul Mullen

University of Glasgow

March 27, 2015
Introduction

1 Overview

2 Summary of the Run 1 $H \rightarrow b\bar{b}$ Analysis

3 A look at the beginnings of the Run 2 Resonance Analysis
Motivation

- Discovery of Higgs decaying into ZZ, WW and $\gamma\gamma$
- Branching fraction to $b\bar{b}$ is much larger but the backgrounds are also much larger. See the LHC Higgs cross section working group
- Alternative is to exploit associated production VH, $t\bar{t}H$ to search for $H \rightarrow b\bar{b}$
- The leptons from the vector boson are useful for triggering and to suppress background
Run 1 $H \rightarrow bb$

- The Run 1 Hbb analysis has been published. The paper can be found [here](#).
- Multivariate discriminant used to enhance sensitivity of the search.
- Cut based analysis also performed and is discussed [here](#).
- Events analysed separately depending on the number of leptons in the final state ($Z \rightarrow \nu\nu, W \rightarrow l\nu, Z \rightarrow ll$) Focussing on the 1 lepton here.

![Diagrams](#)
Event Selection

- **Jet Cuts:**
  - Exactly 2 b-tagged jets (using a jet radius of 0.4)
  - Veto events with extra jets
  - $p_T > 45$ GeV for leading jet, $p_T > 20$ GeV for subleading

- **Lepton Cuts:**
  - Exactly 1 lepton (electron or muon)
  - $|\eta| < 2.5$ and $p_T > 25$ GeV

- Split into $p_T^V$ regions
b-tagging

- neural net based tagger that uses track impact parameter significance and decay vertex reconstruction
- Identify 3 working points for the tagger with increased purity (and reduced efficiency)
- loose: 80%, medium: 70% and tight: 50%
- Classifying events according to the three purity regions helps improve the sensitivity by constraining background from events without real b-jets
The biggest backgrounds to the $l\nu bb$ signal are $W+$jets and $t\bar{t}$. Other backgrounds that play a role are single top, diboson and QCD.

All shapes except the QCD are estimated using Monte Carlo. For the QCD background we use a data driven technique.
QCD estimation

- To estimate the QCD background we change the lepton isolation cuts.
- The isolation cuts are relaxed and events that passed the previous cuts are rejected from this new selection.
- This should give us a sample consisting largely of QCD events and therefore the shape of the background.
- A likelihood fit to data is performed using the EW background and this QCD sample. The MET variable is used in the fit.
- The fits are done separately in the 0 b-tag, 1 b-tag and 2 b-tag inclusive regions.
Overview

Summary of the Run 1 $H \rightarrow b\bar{b}$ Analysis

A look at the beginnings of the Run 2 Resonance Analysis

Plots

**ATLAS** Work In Progress

$\sqrt{s} = 8$ TeV $\int L dt = 20.3$ fb$^{-1}$

$1 e, 2$ Jet, 2 $b$-tag incl., Incl

- **Pink** is QCD
- **Yellow** is $t\bar{t}$
- **Green** is $W+\text{Jets}$

The distributions resulting from the QCD fit give good data to montecarlo agreement
MVA result: $\hat{\mu} = 0.65^{+0.43}_{-0.40}$ at 125 GeV

The MVA result is closer to the standard model expectation
Run 2 VH Resonances

- A few models predict heavy resonances decaying into VH
- Heavy resonance cross sections increase a lot at 13 TeV. For more information look here
- Can get interesting results on the first few fb⁻¹ of data
- A lot of the work will feed back into run 2 H → b¯b searches

![Graph showing luminosity ratios: gg, Σqq, qg]
Boosted Analysis

- VH resonances will be sensitive for very high $p_T$ or "boosted" events
- Challenging as the two b-jets will start to merge into one
- Use large radius jet algorithm (1.0) and select events with a high $p_T$ jet, a lepton and veto events with an additional b-jet
Reducing $t\bar{t}$

- A challenge for both analyses will be the $t\bar{t}$ background which will increase by a factor of 3.3 at 13 TeV.
- At high $p_T$ the increase relative to signal is less severe.
- To reconstruct $t\bar{t}$ as VH we need to miss some of the decay products.
- Larger momentum imbalance in these events can be exploited.
Possibly Interesting Variables

- There are a few variables that can discriminate between signal and background
- Room to optimise
Signal Efficiency

Signal Efficiency versus Background Rejection

ATLAS Simulation Work In Progress
\( \sqrt{s} = 13 \text{ TeV} \)

- vh_vec_scal_ratio
- vh_pt
- additional_jet_sumpt
Overview
Summary of the Run 1 $H \rightarrow b\bar{b}$ Analysis
A look at the beginnings of the Run 2 Resonance Analysis

VH $P_T$ vector to scalar ratio

- Top left is no cuts
- Top right is 50% signal efficiency ($\text{ratio} < 0.05$ & jet mass $> 85$ GeV)
- Bottom left is 90% signal efficiency ($\text{ratio} < 0.20$ & jet mass $> 25$ GeV)
Optimising Sensitivity for Previous Variable

*ATLAS Simulation* Work In Progress  
\[ \sqrt{s} = 13 \text{ TeV} \]
Conclusion

- VH run 1 analysis concluded and published, good result we hope to improve on in run 2
- Work underway on the resonance analysis which should also help to improve the run 2 $H \rightarrow b\bar{b}$ analysis
- Have investigated some promising variables for suppressing the $t\bar{t}$ background.
Overview

Summary of the Run 1 $H \rightarrow b\bar{b}$ Analysis

A look at the beginnings of the Run 2 Resonance Analysis

BACKUP
Other Cuts

- $\Delta R(j, j) > 0.7$ (for $P_T^V < 200$ GeV)
- Remove jets with $P_T < 20$ GeV and $\eta < 2.5$
- Remove jets with $P_T < 30$ GeV and $2.5 < \eta < 4.5$
- 2, 3 and $> 3$ jet regions
- We require that the $P_T$ sum of the tracks in a cone of 0.2 around the lepton be less than 4% of the lepton $P_T$
- We also require that the sum of the transverse energy of the calorimeter deposits in a cone of 0.3 around the lepton be less that 4% of the total transverse energy of the lepton
- MJ iso cuts: $0.05 < \text{track iso} < 0.12$ for electrons and $0.07 < \text{track iso} < 0.5$ for muons, caloIso cut is relaxed to 0.07, isolation is relaxed to medium++
Further Cuts

- The following $P_T^V$ dependent cuts are also applied:

<table>
<thead>
<tr>
<th>$P_T^V$ bin</th>
<th>0-90</th>
<th>90-120</th>
<th>120-160</th>
<th>160-200</th>
<th>$&gt;200$</th>
</tr>
</thead>
<tbody>
<tr>
<td>MET</td>
<td>-</td>
<td>-</td>
<td>$&gt;20$</td>
<td>$&gt;20$</td>
<td>$&gt;50$</td>
</tr>
<tr>
<td>MEff</td>
<td>$&gt;180$</td>
<td>$&gt;180$</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>MTW</td>
<td>$&lt;120$</td>
<td>$&lt;120$</td>
<td>$&lt;120$</td>
<td>$&lt;120$</td>
<td>$&lt;120$</td>
</tr>
<tr>
<td>$\Delta R(b, b)$</td>
<td>$&gt;0.7$</td>
<td>$&gt;0.7$</td>
<td>$&gt;0.7$</td>
<td>$&gt;0.7$</td>
<td>$&gt;0.7$</td>
</tr>
<tr>
<td>$\Delta R(b, b)$</td>
<td>$&lt;3.4$</td>
<td>$&lt;3.0$</td>
<td>$&lt;2.3$</td>
<td>$&lt;1.8$</td>
<td>$&lt;1.4$</td>
</tr>
</tbody>
</table>

- MEff is the scalar sum of the jets and lepton $P_T$ and the MET
- Rejection factors for MV1c - 26(3) for c-jets and 1400(30) against light jets for tight (loose)
Results

- MVA result: $\hat{\mu} = 1.23 \pm 0.44\,(\text{stat}) \pm 0.41\,(\text{syst})$
- The MVA and di-jet mass analysis are 67% correlated and consistent with a p-value of 8%