Search for SM Higgs decays to a pair of muons at 13 TeV with CMS

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Higgs Physics

Theoretical motivation

Spontaneous symmetry breaking: vacuum expectation value ≠ 0 → particles acquire mass

- Higgs sector studied intensively
- Measured coupling to 3\textsuperscript{rd} gen. & gauge bosons
  - No significant deviations from SM
- Probe coupling of Higgs boson to 2\textsuperscript{nd} gen.
  - Investigate Higgs decay to muons

Possible BSM scenarios with non SM like coupling to 2\textsuperscript{nd} generation

- Two Higgs doublet models
- Specific Single Higgs doublet models

Higgs Physics

Main Challenges of the $h \rightarrow \mu\mu$ analysis

- small branching ratio of the decay to muons $B = 2.18 \cdot 10^{-4}$
- very precise mass resolution of dimuon pair
- irreducible background from Drell-Yan events

Signal Higgs production

Expected number of events $35.9/fb$

- $380.4 \text{ GGF}$
- $29.6 \text{ VBF}$
- $17.6 \text{ VH}$
- $3.9 \text{ t\bar{t}H}$

( theoretical SM expectation)

Dominant Background: $qq \rightarrow Z/\gamma^* \rightarrow \mu\mu$ and $gg \rightarrow t\bar{t} \rightarrow \mu\mu$ (dileptonic)
Object selection & Event - Preselection

High efficiency selection of objects

Muons
- Isolated
- Reconstructed in tracker and muon chambers
- $\eta < 2.4$ & $P_t > 20$ GeV

Jets
- Loose ID, clustered in cone of $\Delta R = 0.4$
- $\eta < 4.7$ & $P_t > 30$ GeV
- B Jets tagged with secondary vertex algorithm
- Cleaned against electrons and muons

Preselection
- Single muon trigger $P_t > 24$ GeV
- 2 opposite charged muons
- At least one muon with $P_t > 26$ GeV, matching the Trigger muon

Muon momentum calibration
- Observed $\phi$ modulation in high $\eta$
- Correct modulation to improve mass resolution

Corrections: PU reweighting, scale factors, muon momentum calibration
Object selection & Event - Preselection

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Analysis Strategy

Boosted Decision Tree

BDT trained on GGF, VBF, VH
- Dimuon $p_T$
- Dimuon $\eta$
- $|\delta\phi(\mu\mu)|$
- Number of medium b-tags
- $\eta(jet1)$
- $E_T^{miss}$
- Number of forward jets
- $|\delta\eta(jj_1)|$

...additional variables

Simulation work in progress

Transformed BDT response
sum of all signal events in all production processes has a uniform distribution

Dimuon $P_T$ [GeV]
Analysis Strategy

**BDT response**

![BDT response graph]

**Classification method**

*single decision tree*

- Maximize gain function
- Split categories until gain in significance below threshold

\[ \text{GAIN} = \text{SIG}^2_{\text{NEW1}} + \text{SIG}^2_{\text{NEW2}} - \text{SIG}^2_{\text{OLD}} \]

**Input**: transformed BDT response & mass resolution

**Mass resolution**

\[ \max(\eta_1, \eta_2) \]

- **Endcap**
  - FWHM 3.9 GeV
  - *work in progress*  
  - *simulation*

- **Barrel**
  - FWHM 2.8 GeV
  - *work in progress*  
  - *simulation*
Categorization in quantiles of transformed BDT response and max ($\eta_1, \eta_2$)

<table>
<thead>
<tr>
<th>$\eta$ Range</th>
<th>Cat14</th>
<th>Cat13</th>
<th>Cat12</th>
<th>Cat9</th>
<th>Cat6</th>
<th>Cat3</th>
<th>Cat0</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\eta &lt; 0.9$</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>$0.9 &lt; \eta &lt; 1.9$</td>
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<tr>
<td>$1.9 &lt; \eta &lt; 2.4$</td>
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BDT response

- Cat14: $0.47 \frac{S}{\sqrt{B}} \text{ @ FWHM}$
- Cat13: $0.28 \frac{S}{\sqrt{B}} \text{ @ FWHM}$

$\eta_1 < 0.9$
$0.9 < \eta_1 < 1.9$
$1.9 < \eta_1 < 2.4$

$\eta_2 < 0.9$
$0.9 < \eta_2 < 1.9$
$1.9 < \eta_2 < 2.4$
Results

- $\frac{S}{S+B}$ weighted events for all categories
- Fit function: (modified) Breit-Wigner, Bernstein polynomials, sum of exponentials
- No excess observed \(\rightarrow\) limit on signal strength
Results

Combination Run1 + Run2

Observed Limit $\mu < 2.68$

Expected Limit $\mu < 1.89$

$\mathcal{B}(h \to \mu\mu) < 5.7 \cdot 10^{-4}$
Conclusion

- Probe the SM Higgs couplings to $2^{nd}$ generation in the lepton sector
- Analysis concept for the search for dimuon Higgs decays
  - Object and Event Selection, Muon momentum calibration
  - BDT used to train and to categorize events
  - Combination Run1 and Run2
    $$\mu < 2.68 \ (1.89) \rightarrow \text{significance} \ 0.98\sigma$$
Thanks for your attention
Outlook - Improvements for 2017

- Reduce set of categories
- Introduce exclusive event categories tailored to all Higgs production mechanism
- Including $t\bar{t}H$: extract events with a b tagged jet

### Signal: $t\bar{t}H$

### Background: $t\bar{t}$, $DY, DiBoson, ttW, ttZ$

- Train BDT to specific $t\bar{t}H$
- Top quark decay: source of additional leptons and jets

<table>
<thead>
<tr>
<th>Muon pair</th>
<th>No additional lepton</th>
<th>Additional lepton</th>
</tr>
</thead>
<tbody>
<tr>
<td>≥ 1 b tagged jet</td>
<td>$tth$ hadronic</td>
<td>$tth$ leptonic</td>
</tr>
</tbody>
</table>

Diagram:
- $t\bar{t}$ production
- $H$ decay to $b\bar{b}$
- $t\bar{t}$ decay to $b\bar{b}l\bar{l}$