The search for top-antitop-Higgs production at CMS

Fabrizio Margaroli (Sapienza and INFN)
on behalf of the CMS collaboration
Higgs and Fermions

- We know there is a Higgs boson in LHC data
Higgs and Fermions

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- It first appeared decaying into two bosons
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See morning session talks
Higgs and Fermions

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- It first appeared decaying into two bosons.
- The big picture is still far from clear, as there are a multitude of loops where new physics might be hiding.
- Not to mention interference between diagrams...
**Higgs and Fermions**

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- it first appeared decaying into two bosons
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- not to mention interference between diagrams...

  See Biswas’s at the poster session

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S.Biswas et al. JHEP 01 (2013) 088  
M.Farina et al. JHEP 05 (2013) 022  
S.Biswas et al. JHEP 07 (2013) 073
A SPECIAL RELATIONSHIP

- Higgs coupling to fermions proceeds via a different lagrangian - interesting!
  - but also very hard to measure See H to bb/tautau talks in this session
- Observing ttH is the only way to directly measure the magnitude of top-Higgs coupling, i.e. $Y_t$
- Our current indirect knowledge: $Y_t = \sqrt{2M_t/\text{vev}} = 0.996\pm0.005$ using latest Tevatron and/or LHC $M_{\text{top}}$

- Does $Y_t=1$ mean a special role of the top quark in EWSB?
- ttH sensitive to several natural new physics scenarios (little Higgs, composite Higgs, Extra Dimensions) where new vector-like quarks decay to top and Higgs: ttH+more
  - early ttH discovery could signal new physics! See Devdatta, Antonella’s talks
Higgs and top cross sections at 8 TeV pp collisions

**Higgs @8 TeV**

- H
- qqH
- WH
- ZH
- ttH

**Top @8 TeV**

- tt
- ttg
- ttW
- ttZ
- ttH

**ttH is the next goal in Higgs physics, and in top physics**
A VERY COMPLEX FINAL STATE

• Cross section is only ~1/200 of the inclusive Higgs production cross section
• Large multiplicity of objects in the final state (signature is dominated by the t/t\bar{t} decays)
• Need to find the best combination of top and Higgs decays to isolate the small signal (130fb)
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In the following, will show CMS results on several $ttH$ decay modes:
- $ttH, H \to bb$, $ttbar \to$ lepton+jets and dilepton
- $ttH, H \to tautau$, $ttbar \to$ lepton+jets
- $ttH, H \to gammagamma$, $ttbar \to$ all decay modes
The CMS detector

Inner tracker: charged particles, vertex, isolation

EM and Hadron calorimeters
photons, isolation

The search for ttH requires all subdetectors!
\( H \rightarrow BB, \ TT \rightarrow LJETS \ OR \ DILEPTON \)

- Identify tops and Higgs via multiple b-tagged jets, leptons (ele/muons) and light flavor jets
- Split into Njet/Nbtag categories to further increase sensitivity
- For each category, use machine learning techniques to discriminate signal from dominant tt +bb/cc/b backgrounds

- Fit over resulting shapes, systematics modify relative normalization and shapes themselves
  - largest systematic is on the poorly known tt+bb/cc/b background
**TT\(H, \ H \rightarrow \text{tautau}\)**

- Select hadronically decaying taus, coming from the Higgs decay, reconstructed via a Particle Flow algorithm

- Select additional b-jets, leptons, light flavor jets consistent with ttbar decays, split into Njets and Nbtags categories

<table>
<thead>
<tr>
<th></th>
<th>4 jets 1 b-tag</th>
<th>5 jets 1 b-tag</th>
<th>(\geq) 6 jets 1 b-tag</th>
<th>4 jets 2 b-tags</th>
<th>5 jets 2 b-tags</th>
<th>(\geq) 6 jets 2 b-tags</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\text{ttH}(125))</td>
<td>0.4 ± 0.1</td>
<td>0.6 ± 0.1</td>
<td>0.6 ± 0.2</td>
<td>0.1 ± 0.0</td>
<td>0.2 ± 0.1</td>
<td>0.4 ± 0.1</td>
</tr>
<tr>
<td>(\text{tt})</td>
<td>225 ± 69</td>
<td>119 ± 38</td>
<td>64 ± 22</td>
<td>48 ± 15</td>
<td>38 ± 12</td>
<td>27.0 ± 9.1</td>
</tr>
<tr>
<td>(\text{ttV})</td>
<td>1.1 ± 0.3</td>
<td>1.3 ± 0.3</td>
<td>1.4 ± 0.4</td>
<td>0.4 ± 0.1</td>
<td>0.6 ± 0.2</td>
<td>1.1 ± 0.3</td>
</tr>
<tr>
<td>Single t</td>
<td>11.2 ± 4.0</td>
<td>3.0 ± 1.4</td>
<td>1.1 ± 1.0</td>
<td>1.9 ± 1.1</td>
<td>0.9 ± 0.6</td>
<td>0.6 ± 0.7</td>
</tr>
<tr>
<td>V+jets</td>
<td>33 ± 17</td>
<td>11.7 ± 6.8</td>
<td>3.8 ± 2.8</td>
<td>1.4 ± 0.9</td>
<td>0.4 ± 0.3</td>
<td>0.5 ± 0.6</td>
</tr>
<tr>
<td>Diboson</td>
<td>0.9 ± 0.2</td>
<td>0.7 ± 0.2</td>
<td>0.1 ± 0.0</td>
<td>0.0 ± 0.0</td>
<td>0.1 ± 0.0</td>
<td>0.1 ± 0.1</td>
</tr>
<tr>
<td>Total bkg</td>
<td>271 ± 82</td>
<td>135 ± 41</td>
<td>71 ± 24</td>
<td>52 ± 16</td>
<td>40 ± 12</td>
<td>29.2 ± 9.4</td>
</tr>
</tbody>
</table>

- Data: 292

- Here \(\text{tt+jets}\) is again dominant background
  - multivariate discriminants exploit mostly tau-related informations

- Total Ns~2.5 evts
  - \(\times 10\) (H \(\rightarrow\) bb, ttbar \(\rightarrow\) dilepton)
  - \(\times 100\) (H \(\rightarrow\) bb, ttbar \(\rightarrow\) l+jets)
A PARTIAL COMBINATION

- No statistically significant excess over background predictions
- \( ttH, \, H \rightarrow bb \) and \( H \rightarrow \text{tautau} \) have been combined to produce statements on sensitivity to this production mode

<table>
<thead>
<tr>
<th>ttH decay mode</th>
<th>Exp</th>
<th>Ob</th>
</tr>
</thead>
<tbody>
<tr>
<td>( H \rightarrow bb, , tt \rightarrow \text{lepton+jets} )</td>
<td>4.7</td>
<td>4.9</td>
</tr>
<tr>
<td>( H \rightarrow bb, , tt \rightarrow \text{dilepton} )</td>
<td>8.2</td>
<td>9.1</td>
</tr>
<tr>
<td>( H \rightarrow \text{tautau}, , tt \rightarrow \text{ljets or dilepton} )</td>
<td>14.2</td>
<td>13.2</td>
</tr>
<tr>
<td>Combination</td>
<td>4.1</td>
<td>5.2</td>
</tr>
</tbody>
</table>

Systematics already taking a hit on the most sensitive channels
HIGGS TO GAMMA GAMMA

- Very low rate, but distinctive signature of the Higgs peak. Backgrounds are coming from top(s) + photon(s), or photons+(b)jets, latter poorly known at theoretical level

- Split into events with leptons and few jets (leptonic) or no leptons and many jets (hadronic)

Event selection minimizes contamination from other Higgs sources

<table>
<thead>
<tr>
<th>Process</th>
<th>Hadronic Channel</th>
<th>Leptonic Channel</th>
</tr>
</thead>
<tbody>
<tr>
<td>$ttH$</td>
<td>0.567 (87%)</td>
<td>0.429 (97%)</td>
</tr>
<tr>
<td>$gg \rightarrow H$</td>
<td>0.059 (9%)</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>VBF $H$</td>
<td>0.006 (1%)</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>$WH/ZH$</td>
<td>0.019 (3%)</td>
<td>0.013 (3%)</td>
</tr>
<tr>
<td>Total signal</td>
<td>0.65</td>
<td>0.44</td>
</tr>
</tbody>
</table>

fitting the diphoton peak greatly reduce sensitivity to background systematics
HIGGS TO GAMMA GAMMA RESULTS

• No significant excess found, combine the two (statistically independent) channels to increase sensitivity

<table>
<thead>
<tr>
<th></th>
<th>Observed</th>
<th>Expected</th>
<th>Expected (No Syst.)</th>
</tr>
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<tr>
<td>Hadronic Channel</td>
<td>6.8</td>
<td>9.2</td>
<td>8.8</td>
</tr>
<tr>
<td>Leptonic Channel</td>
<td>10.7</td>
<td>8.0</td>
<td>7.7</td>
</tr>
<tr>
<td>Combined</td>
<td>5.4</td>
<td>5.3</td>
<td>5.1</td>
</tr>
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• Extract upper limits on ttH cross section

• Interpret the data as a cross section measurement
  – keep in mind that precision on Yt is twice better than on sigma(ttH)!
CONCLUSIONS

• Measurement of Higgs coupling to top quarks especially interesting
• Deviations of top-Higgs coupling from SM, are very possible as our current knowledge comes only from loop-induced diagrams
• Increasing our sensitivity to ttH by combining multiple channels

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<th>ttH decay mode</th>
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<tr>
<td>H → bb, tt → lepton+jets</td>
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<td>8.2</td>
<td>9.1</td>
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<tr>
<td>H → tautau, tt → jets or dilepton</td>
<td>14.2</td>
<td>13.2</td>
</tr>
<tr>
<td>H → gamma gamma, tt → all jets</td>
<td>9.2</td>
<td>6.8</td>
</tr>
<tr>
<td>H → gamma gamma, tt → leptons</td>
<td>8.0</td>
<td>10.7</td>
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– already beating benchmark extrapolations for top-Higgs coupling
– still lots can be said before LHC run at higher energies

Here MH = 125 GeV
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Exploring top-Higgs relation at 360 degrees: stay tuned!
BACKUP
HIGGS PRODUCTION AND DECAY

![Graphs and diagrams showing Higgs boson production processes and branching ratios.](image-url)
HIGGS AND FERMIONS
HIGGS BRANCHING RATIOS

• It is interesting to interpret $ttH$ results on the $C_t$, $C_V$ plane.
• $\sigma(ttH)$ proportional to $Y_t^2 \rightarrow C_t^2$
• Higgs decays have a complex dependence on $C_t$ and $C_V$
• The different decay modes explored here probe different regions of the $C_t$ and $C_V$ plane

Taken from S. Biswas et al, compatible results from HDECAY
# Systematics on ttH, H→bb

Uncertainties on the sum of tt+lf, tt+b, tt + bb, and tt + c+c events with ≥ 6 jets and ≥ 4 b-tags

<table>
<thead>
<tr>
<th>Source</th>
<th>Rate</th>
<th>Shape?</th>
</tr>
</thead>
<tbody>
<tr>
<td>QCD Scale (all tt+hf)</td>
<td>35%</td>
<td>No</td>
</tr>
<tr>
<td>QCD Scale (tt + bb)</td>
<td>17%</td>
<td>No</td>
</tr>
<tr>
<td>b-Tag hf contamination</td>
<td>17%</td>
<td>Yes</td>
</tr>
<tr>
<td>QCD Scale (tt + cc)</td>
<td>11%</td>
<td>No</td>
</tr>
<tr>
<td>Jet Energy Scale</td>
<td>11%</td>
<td>Yes</td>
</tr>
<tr>
<td>b-Tag lf contamination</td>
<td>9.6%</td>
<td>Yes</td>
</tr>
<tr>
<td>b-Tag hf stats (linear)</td>
<td>9.1%</td>
<td>Yes</td>
</tr>
<tr>
<td>QCD Scale (tt+b)</td>
<td>7.1%</td>
<td>No</td>
</tr>
<tr>
<td>Madgraph Q^2 Scale (tt + bb)</td>
<td>6.8%</td>
<td>Yes</td>
</tr>
<tr>
<td>b-Tag Charm Uncertainty (quadratic)</td>
<td>6.7%</td>
<td>Yes</td>
</tr>
<tr>
<td>Top Pt Correction</td>
<td>6.7%</td>
<td>Yes</td>
</tr>
<tr>
<td>b-Tag hf stats (quadratic)</td>
<td>6.4%</td>
<td>Yes</td>
</tr>
<tr>
<td>b-Tag lf stats (linear)</td>
<td>6.4%</td>
<td>Yes</td>
</tr>
<tr>
<td>Madgraph Q^2 Scale(tt + 2 partons)</td>
<td>4.8%</td>
<td>Yes</td>
</tr>
<tr>
<td>b-Tag lf stats (quadratic)</td>
<td>4.8%</td>
<td>Yes</td>
</tr>
<tr>
<td>Luminosity</td>
<td>4.4%</td>
<td>No</td>
</tr>
<tr>
<td>Madgraph Q^2 Scale (tt + cc)</td>
<td>4.3%</td>
<td>Yes</td>
</tr>
<tr>
<td>Madgraph Q^2 Scale (tt+b)</td>
<td>2.6%</td>
<td>Yes</td>
</tr>
<tr>
<td>Lepton ID/Trig</td>
<td>1.4 (2.8)%</td>
<td>No</td>
</tr>
<tr>
<td>QCD Scale (tt)</td>
<td>3%</td>
<td>No</td>
</tr>
<tr>
<td>pdf (gg)</td>
<td>2.6%</td>
<td>No</td>
</tr>
<tr>
<td>Jet Energy Resolution</td>
<td>1.5%</td>
<td>No</td>
</tr>
<tr>
<td>Pileup</td>
<td>1%</td>
<td>No</td>
</tr>
<tr>
<td>b-Tag Charm Uncertainty (linear)</td>
<td>0.6%</td>
<td>Yes</td>
</tr>
</tbody>
</table>
EVENT DISPLAY $H \rightarrow bb$
PRE AND POST FIT

Pre-fit

Post-fit
EVENT DISPLAY H→PHOTONS

CMS Experiment at LHC, CERN
Data recorded: Sat Nov 24 19:16:36 2012 CEST
Run/Event: 207889 / 771018991
Lumi section: 783
EVENT DISPLAY $H \rightarrow \text{PHOTONS}$

CMS Experiment at LHC, CERN
Data recorded: Thu Nov 1 02:13:01 2012 CEST
Run/Event: 206446 / 1072391444
Lumi section: 784
TECHNICALITIES

Signal and background modeling

- \( ttH, WW, WZ, ZZ \) Pythia
- \( ttW/ttZ/ttgamma/ttgamgamama/gamma+jets/ gammagamma+jets \) MadGraph
- \( tq/tW \) Powheg

btagging

- Combined secondary vertex, medium OP
- \( H->bb \) also uses full CSV spectrum

Triggers used:

- Diphoton trigger
- Electron trigger
- Muon trigger
- \( ee/emu/mumu \) triggers