Searches for a high-mass Higgs boson in the ZZ and WW decay channels with the CMS detector

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Outline of the talk

• Motivation of the search
• Decays into $WW$:
  $\Rightarrow WW \rightarrow l\nu l\nu$ final state
  $\Rightarrow WW \rightarrow l\nu j(j)$ final state
• Decays into $ZZ$:
  $\Rightarrow ZZ \rightarrow 4l$ final state
  $\Rightarrow ZZ \rightarrow ll\nu\nu$ final state
  $\Rightarrow ZZ \rightarrow llj(j)$ final state
• Combination of the results and conclusions
Motivation of the search

• A candidate for the SM Higgs boson has been found at 125 GeV... see other talks in the session!!

Now searching for similar Higgses at higher masses

• Searches with the SM parameters as “benchmark” reference.
• Unrealistic due to $h(125)$ but reasonable approach.
• Characteristics:
  ⇒ Diboson ($ZZ/WW$) decays are dominant (and motivated by EWKSB).
  ⇒ Main production channels ($ggH$, VBF).

• Another model that we are using is the so-called “EWK-singlet”.

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The EWK singlet model (in a nutshell)

- Addition of an EW singlet field to the SM scalar sector, acquiring a non-zero vacuum expectation value.
- Providing a possible answer to the problem of the dark matter.
- Two mixing CP-even states:
  - Light state is the $h(125)$.
  - Heavy state is still to be found, but similar to the SM.
- Properties of the Higgs are modified accordingly to the following expressions:

<table>
<thead>
<tr>
<th>Light state</th>
<th>Heavy state</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma_h \times BR_h = C^2 \times \sigma_{SM} \times BR_{SM}$</td>
<td>$\sigma_H \times BR_H = C'^2 \times (1 - BR_{new}) \times \sigma_{SM}$</td>
</tr>
<tr>
<td>$\Gamma_h = C^2 \times \Gamma_{SM}$</td>
<td>$\Gamma_H = \frac{C'^2}{(1 - BR_{new})} \times \Gamma_{SM}$</td>
</tr>
<tr>
<td>$\mu_h = \frac{\sigma_h \times BR_h}{\sigma_{SM} \times BR_{SM}} = C^2$</td>
<td>$\mu_H = C'^2 \times (1 - BR_{new})$</td>
</tr>
</tbody>
</table>

being $BR_{new}$ a value to account for possibles new decays of the heavy state (e.g. $H \rightarrow hh$).
Higgs in the leptonic \( WW \rightarrow l\ell l\ell \) channel

- Cleanest channel for \( H \rightarrow WW \) that is investigated in all possible forms:
  - In bins of jet multiplicities
  - In main modes: \( ggH \) and VBF
  - Also \( ZH \) and \( WH \) (even semileptonic)

- Kinematic differences exploited to maximize sensitivity.

- High-mass coverage independent of mass (up to 600 GeV).

- All results and combination available in
  
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(See also talk by Pietro Govoni yesterday)
The semileptonic $WW$ ($H \rightarrow WW \rightarrow \ell\nu jj$)

- To gain sensitivity at high masses, using $W$ hadronic decays.
- $m(W[\ell\nu])$ constraint for complete $WW$ mass ($m(W) \rightarrow p_{z,\nu}$).
- Using dijet mass to reduce QCD-induced background!

- Shape analysis of $m(WW)$ to look for resonance and extract limit.
- Results interpreted for SM-like Higgs and EWK singlet model.
- NEW Result! (see CMS PAS HIG-13-027)
Boosted-jet topology: \( H \rightarrow WW \rightarrow l\nu J \)

- To reach higher masses, need to take into account that the bosons are boosted and their decay products get merged.
- Specific reconstruction needed for going beyond 600 GeV.

Large-radius jets (CA8)

Internal topology (subjets)

Identify jet as \( W \rightarrow qq' \)

High sensitivity!!!
Higgs in the $ZZ$ decay

- Decay to $ZZ$ is studied in addition to $WW$.
- The cleanest fully-leptonic decay provides one golden channel to study the particles decaying to $ZZ$.
- Sensitive to the $h(125)$ but also to resonance at higher masses.
- All possible channels and production modes studied.
- High precision achievable with this channel: simple background.
- Statistically limited, so will improve a lot in Run 2 (including high-mass resonances).
- Also including $ll\tau\tau$ channel.

More information about these final states on specific talks.

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The $ZZ$ dilepton channel: $H \rightarrow ZZ \rightarrow ll\nu\nu$

When going to higher masses the weight of the BR becomes larger, and the cleanest channel ($4l$ and $ll\tau\tau$) loses relevance.

- The most relevant gains a factor $>2$ with the neutrino decay.
- Also the topology (boosted $Z$ from very massive object) benefits this final state.

Most sensitive channel for $X \rightarrow ZZ$ at the high end
$H \rightarrow ZZ \rightarrow ll\nu\nu$: EWK singlet interpretation

- Results are also interpreted in the EWK singlet model.
- Multiparameter space: $m_H$, $C'^2$ and $BR_{\text{new}}$

- It should be noted that there are large correlations with how much SM-like is the $h(125)$.
- e.g. $\mu_h \rightarrow 1$ implies less sensitivity to $H$ (excluded high $C'^2$).
The $ZZ$ semileptonic decay: $H \rightarrow ZZ \rightarrow lljj$

- As the $W$, $Z$ decays mostly to hadrons.
- The semileptonic channel allows to get a high yield but with a huge background.

but the full final state is reconstructed:
  - Mass fully reconstructed.
  - Discrimination using angular variables for spin-0 candidates.
  - Exploiting $b$-tagging ($Z \rightarrow b\bar{b}$)

It is a difficult final state due to the jets, that complicates the extension of the main search to high masses (merged jets) or VBF.

- Still nice sensitivity for medium masses.
- Working on extensions right now!
Combination, conclusions and prospects

- All the previous results are being combined for the global limit.
- Expecting very high sensitivity and complementarity due to the variety of channels.
- Last $H(ZZ)$ combination shows those are achievable:

- Reinterpreting the data as a search for EWK singlet.
- Now completing the results and obtaining final combination.

CMS Run-I publication of these searches soon!!!
BACKUP SLIDES
Boosted jets and boson tagging

- The large energy available at the LHC allows a large cross section to the production of high-$p_T$ “massive” objects.
- “Boosted” in the detector frame.
- Similar effect from the decays of very heavy particles decaying to $W, Z, t$.
- Need of a new approach for leptons and jets to identify them.
- For jets using characteristics of the internal structure (subjets) and specific kinematic reconstructions (mass-drop, pruning, . . . )

- Standard & Common use for

  W-tagging: see CMS PAS JME-13-006
  top-tagging: see CMS PAS JME-13-007

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