Higgs to WW measurements at CMS
Since the observation of a new particle in 2012, mass and spin have been measured by ATLAS and CMS experiments.

Higgs boson properties measurements are an excellent Standard Model test and give hints for Beyond SM physics.

One of the most sensitive decay channel is $H \rightarrow WW \rightarrow 2\ell 2\nu$

Key channel for Higgs boson couplings.


See ttH section
Run-I H → WW results

The ATLAS and CMS Collaborations - JHEP 1608 (2016) 045 -

**ATLAS**: obs (exp) 6.8σ (5.8σ) and μ = 1.22^{+0.23}_{-0.21}

**CMS**: obs (exp) 4.8σ (5.6σ) and μ = 0.90^{+0.23}_{-0.21}

**ATLAS + CMS**: μ = 1.09^{+0.18}_{-0.16}

Excellent agreement with data in WW channel.

WW channel gives one of the most precise measurement of the Higgs boson coupling.
H → WW → $2\ell2\nu$ at 13 TeV in CMS

**Signal:** two charge opposite lepton pair, neutrinos and various number of jets.

- The neutrinos in the final state escape direct detection and lead to large MET: impossible to reconstruct the Higgs invariant mass spectrum.
- Transverse mass used to study Higgs boson properties.

$$m^H_T = \sqrt{2p_T \slashed{E}_T^{\text{miss}}(1 - \cos \Delta \phi(\ell\ell, \slashed{E}_T^{\text{miss}}))},$$

**Preselection:**

- Two opposite charge leptons with $p_{T1} > 25$ GeV and $p_{T2} > 10(13)$ GeV for $\mu(e)$.
- MET > 20 GeV, $p_{T\ell\ell} > 30$ GeV.
- Only jet with $p_T > 30$ GeV, no overlap with leptons.
- b-tagged jet veto.
Main backgrounds: several processes can lead to the similar event properties.

- **WW → ℓνℓν**
  - Same final state of the signal. Different kinematic properties of lepton system.

- **tt→WWbb→ℓνℓνbb**
  - Very large xsec. Same final state of the signal. Characterized by b-jet. Normalization from data in control regions.

- **DY → ℓℓ**
  - Very large xsec for the same flavour final state. Normalization estimated in data control regions.

- **W +jets → ℓν +jets**
  - Fake lepton from a misidentified jet. Reduced with ID and isolation requirements.

Other background processes with Z bosons, such as WZ/Wγ*, ZZ* with a misidentified lepton and Zγ with γ conversion are relevant in WH production mode.
Events categorized according to the number of **leptons**, the number of **jets** and the **kinematics** of the jets.

- The **0** and **1-jet** categories are split in Same Flavour (SF) and Different Flavour (DF) and target on gluon fusion production mechanism.
- The **2-jet** is split according the gluon fusion, VBF and VH production mechanism.
Gluon Fusion categories

- **Different Flavour**: analysis based on bi-dimensional templates of $m_\ell \ell$ vs $m_{T_2}$: the distributions are used for the signal extraction.

- **Same Flavour**: events counting analysis optimized with a BDT.

  - **W+jet background reduction**: events split in lepton-flavour-charge and in accordind to $p_{T_2}$ of the subleading lepton (cut on 20 GeV).

- **$p_{T_2}$ <20 GeV**

- **$p_{T_2}$ >20 GeV**
Vector Boson Fusion, VH, WH and ZH categories

- **VBF**: characterized by pair of forward-backward jets. The analysis based is on $m_{ll}$ distribution. Split in two region $400 < m_{jj} < 700$ GeV and $m_{jj} > 700$ GeV.

- **VH with 2 jets**: $W$ or $Z$ decays in two resolved jets. Two jets invariant mass in $[65, 105]$ GeV. Analysis based on $m_{ll}$ distribution.

- **WH with 3 leptons**: fourth lepton veto. Two sub-categories: Same-Sign-Same-Flavour $\mu^\pm \mu^\pm e^\mp/e^\mp e^\mp \mu^\mp$ and Opposite-Sign-Same-Flavour $\mu^\mp \mu^\pm e^\mp/e^\mp e^\mp \mu^\mp$. Template fit on minimum $\Delta R$ between opposite-charged leptons.

- **ZH with 4 leptons**: exactly 4 isolated leptons with tight ID criteria and zero total charge. Results is extracted from events counting analysis.
Results I

Signal strengths and Significance

CMS Run-I significance results for VBF and ggF separately

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<th>( \mu_{WW} )</th>
<th>( \mu_{ggF} )</th>
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<tbody>
<tr>
<td>VBF</td>
<td>1.08 ±0.65</td>
<td>0.84 ±0.25</td>
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<tr>
<td>ggF</td>
<td></td>
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**First observation Higgs to WW**

\[
\mu = 1.28^{+0.18}_{-0.17} = 1.28 \pm 0.10(\text{stat}) \pm 0.11(\text{syst})^{+0.10}_{-0.07}(\text{theo})
\]

Significance = 9.1\( \sigma \)(7.1\( \sigma \) exp)
To explore Higgs boson couplings is necessary to separate between ggF and the other contribution (VBF/VH).

- In ggF, the Higgs boson's coupling to fermions is involved by virtual loop.
- In the other mechanism, the tree level coupling to vector boson play a central role.

Crucial contribution in the Higgs combined coupling measurements
Studies on the Higgs boson properties are essential to understand the nature of the Higgs boson.

- CMS results with \( \mathcal{L} = 35.9 \text{ fb}^{-1} \) for ggF, VBF and VH production mechanisms.
- First observation of Higgs to WW (\( > 9\sigma \))
- Coupling measurements are in agreement with the SM prediction within 2\( \sigma \).

Stay tuned for other Higgs to WW results (i.e. high mass searches).
backup
The Higgs boson in the Standard Model

**Higgs boson production processes**

- ggH: 48.58 pb
- qqH: 3.78 pb
- WH+ZH: 2.38 pb
- ttH+bbH: 1.0 pb

xsec @ 13 TeV

**Higgs boson decays**

- WW: 21%
- gg: 9%
- bb: 57%
- cc: 6%
- ZZ: 3%
- Other: 1%

**WW channel** has the second largest **Branching Ratio** and a reasonable level of irreducible background.
Vector Boson Fusion, VH, WH and ZH categories

**VBF**: characterized by pair of forward-backward jets. The analysis is based on $m_{\ell\ell}$ distribution. Split in two regions $400 < m_{jj} < 700$ GeV and $m_{jj} > 700$ GeV.
Results III

- Signal strengths and Significance in each categories
Observed cross sections for the main Higgs boson production modes, normalized to the SM predictions.