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# Higgs to WW measurements at CMS

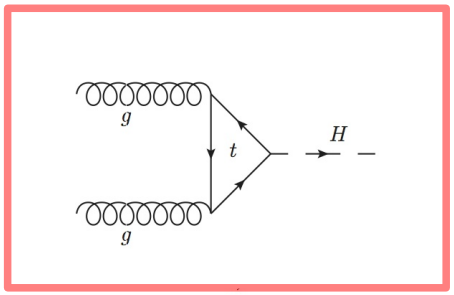
Higgs Hunting, July 23-25, 2018, Orsay-Paris, France

# Introduction

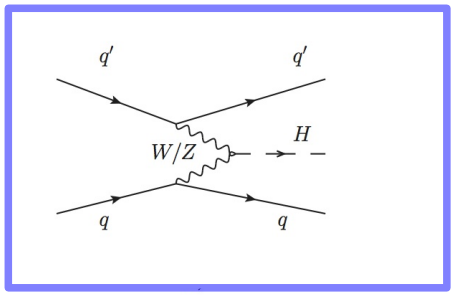
- Since the observation of a new particle in 2012, mass and spin have been measured by ATLAS and CMS experiments.
  - Higgs boson properties measurements are an excellent Standard Model test and give hints for Beyond SM physics.

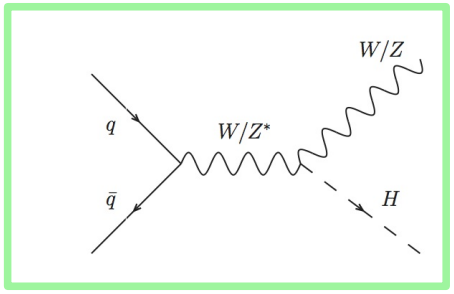
- One of the most sensitive decay channel is **H → WW →** $2\ell 2\nu$
  - Key channel for Higgs boson couplings.

Gluon fusion

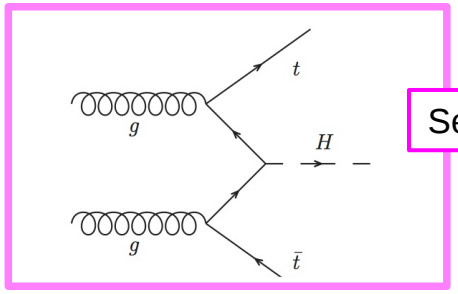



Vector Boson Fusion




Vector boson associated production




See ttH section

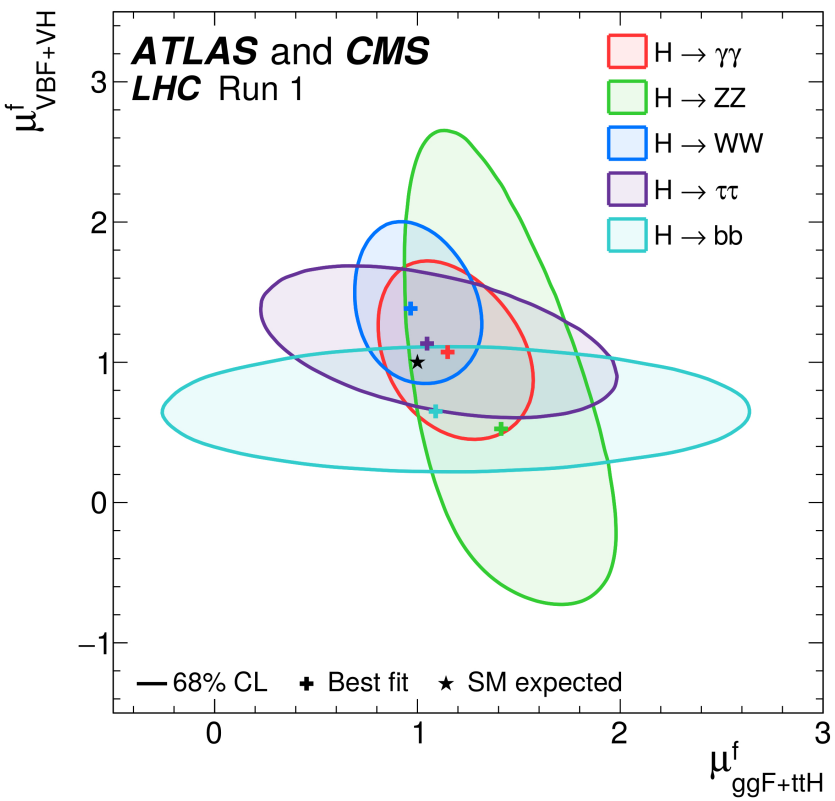
Top boson associated production

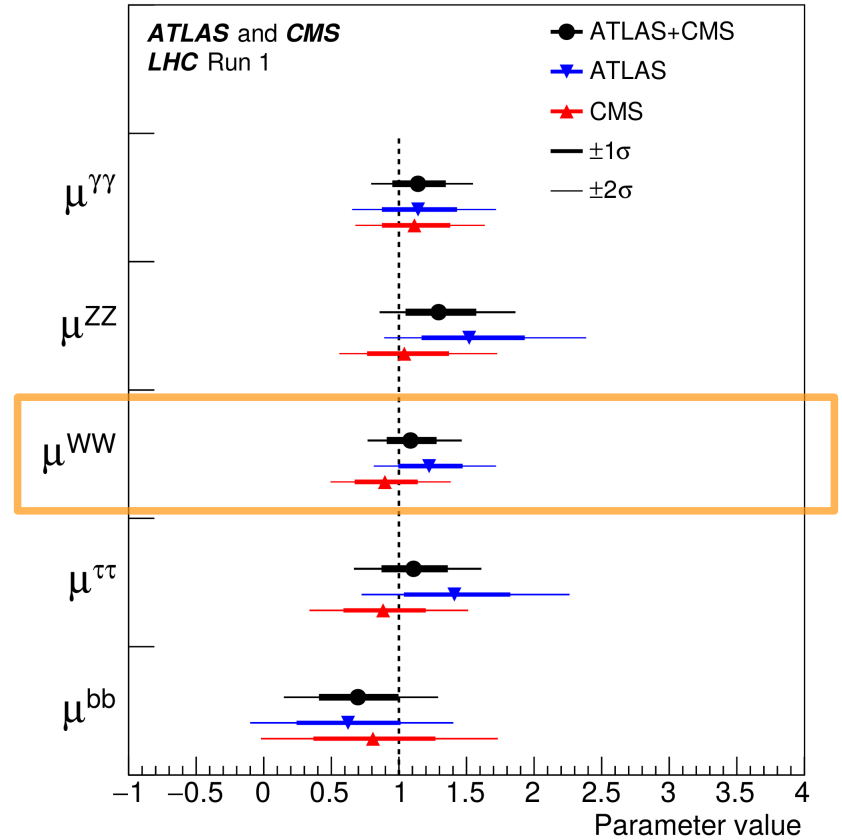
- New CMS results with 35.9 $fb^{-1}$, submitted to PLB. CMS-HIG-16-042, arXiv:1806.05246

# Run-I H → WW results

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

- **ATLAS**: obs (exp) 6.8σ (5.8σ ) and $\mu = 1.22^{+0.23}_{-0.21}$
- **CMS**: obs (exp) 4.8σ (5.6σ ) and $\mu = 0.90^{+0.23}_{-0.21}$
- **ATLAS + CMS**: $\mu = 1.09^{+0.18}_{-0.16}$
- Excellent agreement with data in WW channel.

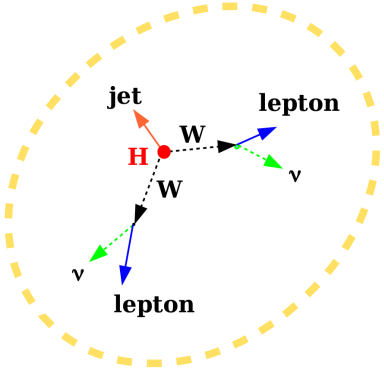


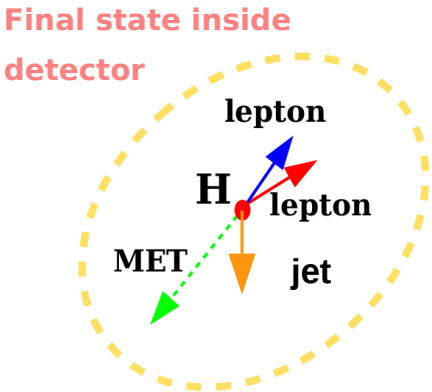

- WW channel gives one of the most precise measurement of the Higgs boson coupling.

# H → WW → $2\ell 2\nu$ 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.



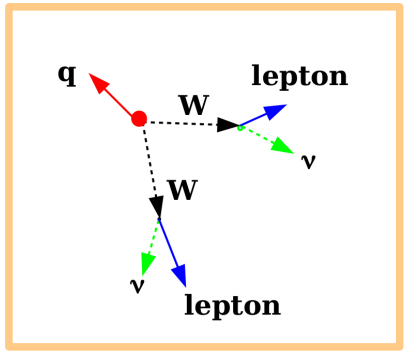

$$m_{\mathrm{T}}^{\mathrm{H}} = \sqrt{2 p_{\mathrm{T}}^{\ell\ell} E_{\mathrm{T}}^{\mathrm{miss}} (1 - \cos \Delta\phi(\ell\ell, \vec{E}_{\mathrm{T}}^{\mathrm{miss}}))},$$

- **Preselection:**
  - Two opposite charge leptons with $p_{T1}$ >25 GeV and $p_{T2}$ >10(13) GeV for μ(e).
  - MET>20 GeV, $p_{Tll}$ >30 GeV.
  - Only jet with $p_T$ >30 GeV, no overlap with leptons.
  - b-tagged jet veto.

# Backgrounds for the Higgs boson to WW

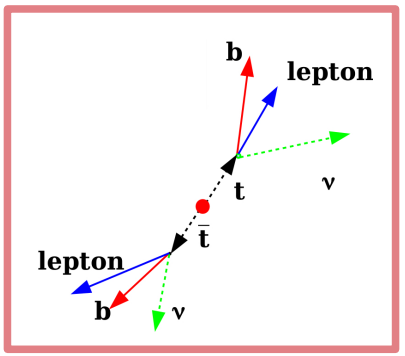
- **Main backgrounds**: several processes can lead to the similar event properties.

**WW → ℓνℓν**



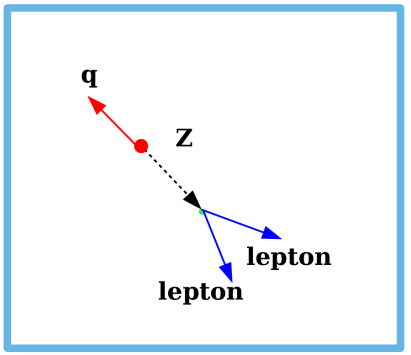

Same final state of the signal. Different kinematic properties of lepton system

**tt→WWbb→ℓνℓνbb**



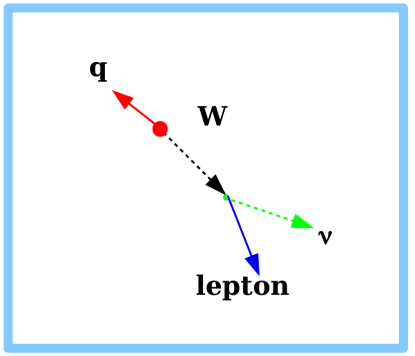

Very large xsec. Same final state of the signal. Characterized by b-jet. Normalization from data in control regions

**DY →ℓℓ**




Very large xsec for the same flavour final state. Normalization estimated in data control regions.

**W +jets → ℓν +jets**

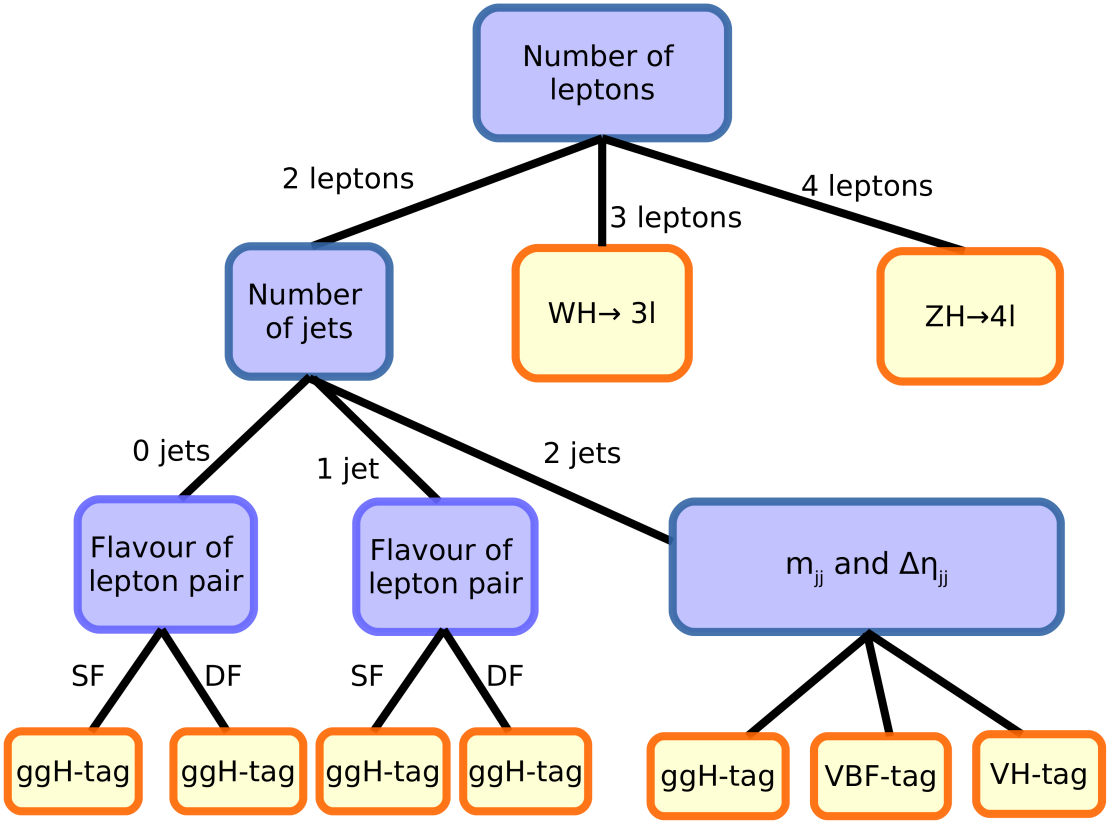



Fake lepton from a misidentified jet. Reduced with ID and isolation requirements.

- Other background processes with Z bosons, such as WZ/W$\gamma^*$, ZZ$^*$ with a misidentified lepton and Z$\gamma$ with $\gamma$ conversion are relevant in WH production mode.

# Events categorization

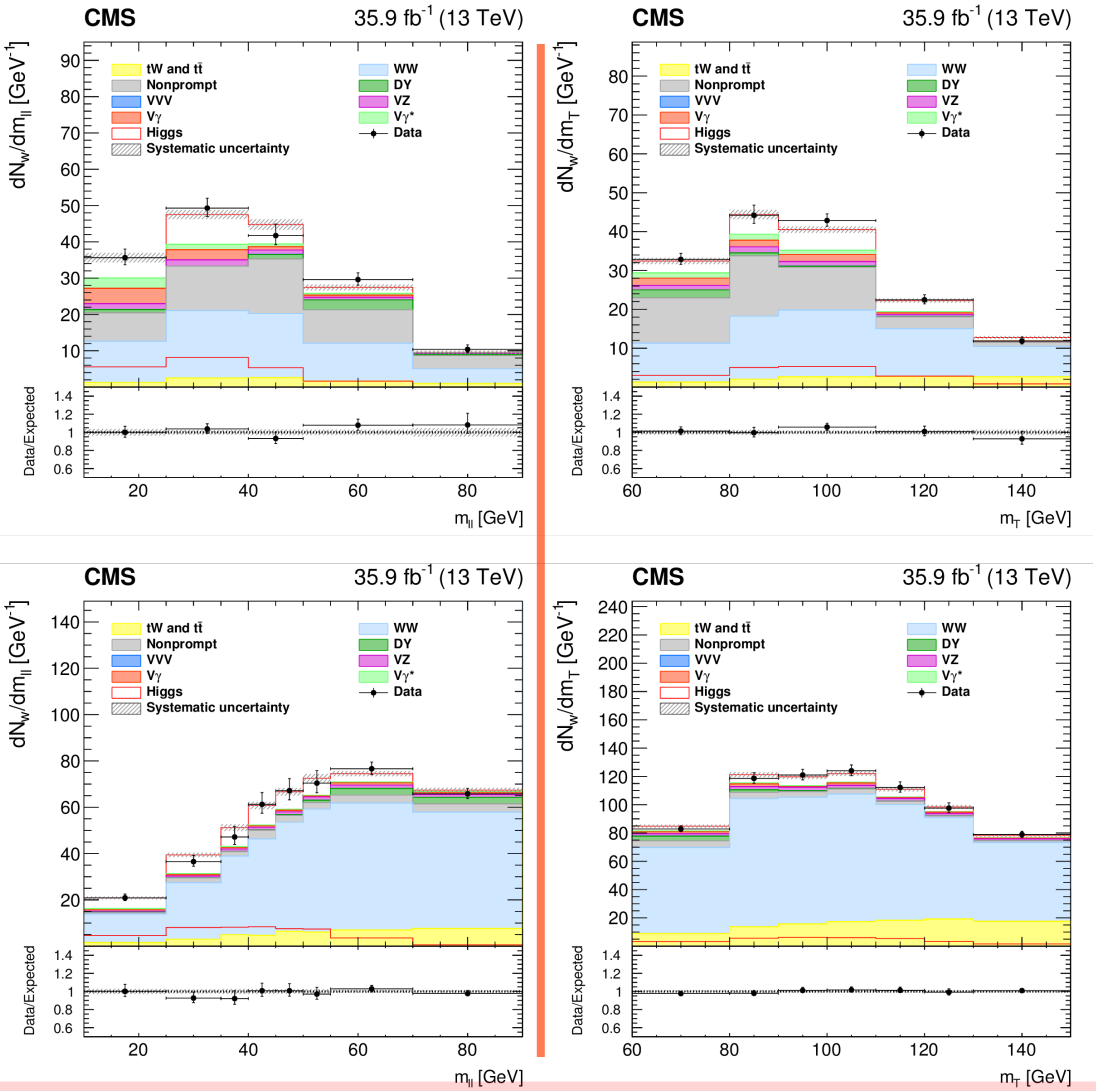
- Events categorized according to the number of **leptons**, the number of **jets** and the **kinematics** of the jets.
  - The **0** and **1-jet** categories are split in Same Flavour (**SF**) and Different Flavour (**DF**) and target on gluon fusion production mechanism.
  - The **2-jet** is split 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 $m^H_T$: 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 $p_{T2}$ of the subleading lepton (cut on 20 GeV).

$p_{T2}$ <20 GeV

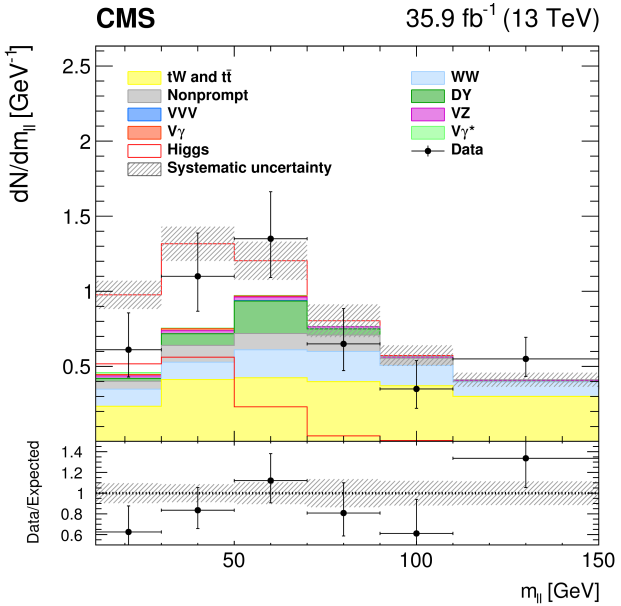



$p_{T2}$ >20 GeV

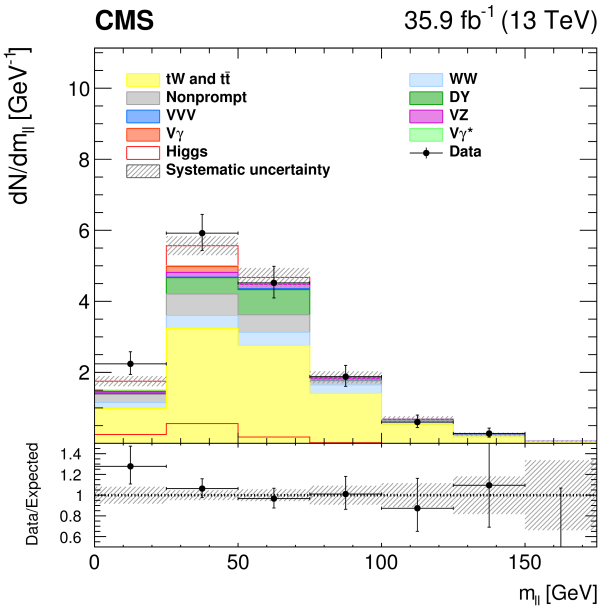
# Vector Boson Fusion, VH, WH and ZH categories

- **VBF**: characterized by pair of forward-backward jets. The analysis based is on m $\ell\ell$ distribution. Split in two region 400<mjj<700 GeV and mjj>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$\ell\ell$ distribution.
- **WH with 3 leptons**: fourth lepton veto. Two sub-categories: Same-Sign-Same-Flavour $\mu^{\pm}\mu^{\pm}e^{\mp}/e^{\pm}e^{\pm}\mu^{\mp}$ and Opposite-Sign-Same-Flavour $\mu^{\mp}\mu^{\pm}e^{\mp}/e^{\mp}e^{\pm}\mu^{\mp}$. Template fit on minimum ΔR between opposite-charged leptons.
- **ZH with 4 leptons**: exaclty 4 isolated leptons with tigh ID criteria and zero total charge. Results is extracted from events counting analysis.

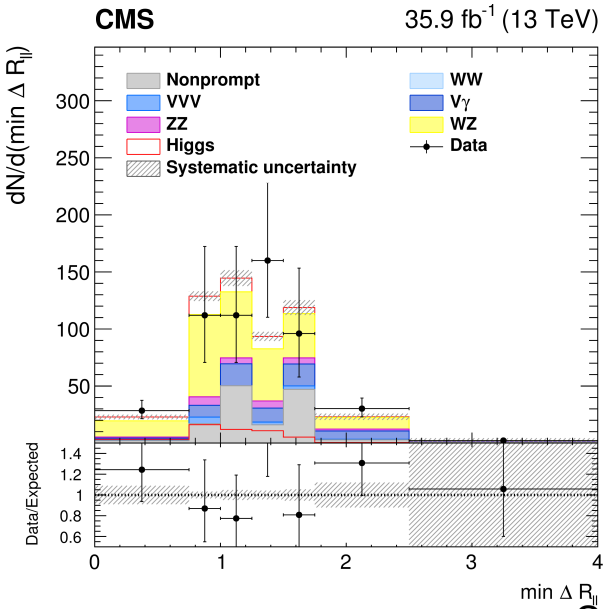
**VBF, mjj>700 GeV, higher purity region**




**VH+2jets**

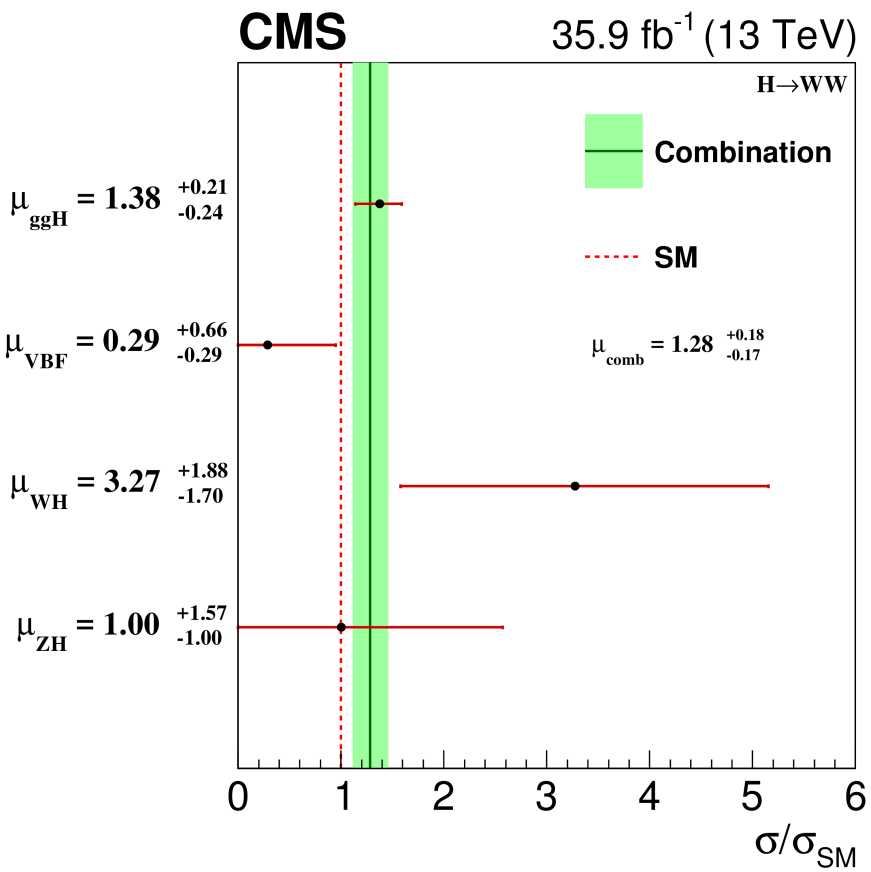



**WH**



# Results I

- **Signal strengths and Significance**




| CMS **Run-I** significance results for VFB and ggF separately | |
|---|---|
| $\mu^{WW}_{VBF}=1.08^{+0.65}_{-0.58}$ | $\mu^{WW}_{ggF}=0.84^{+0.25}_{-0.21}$ |

**Combination**

$$\mu = 1.28^{+0.18}_{-0.17} = 1.28 \pm 0.10(\text{stat}) \pm 0.11(\text{syst})^{+0.10}_{-0.07}(\text{theo})$$
$$\text{Significance} = 9.1\sigma(7.1\sigma\ \text{exp})$$

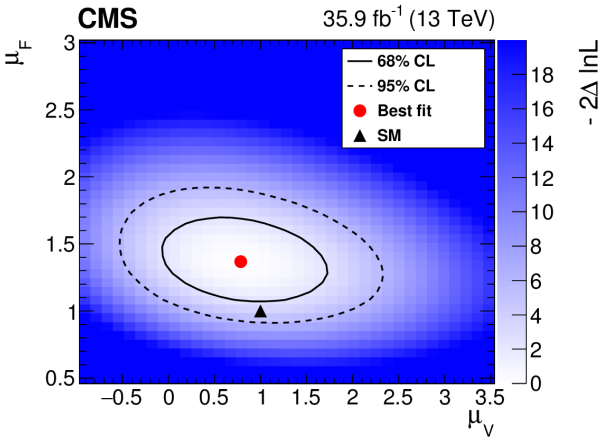
**First observation Higgs to WW**

# Results II

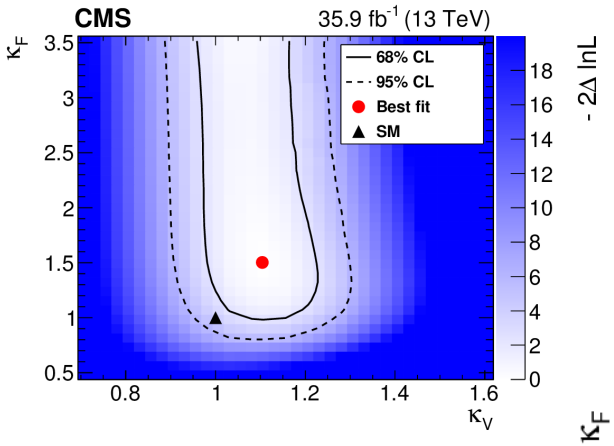
- To explore Higgs boson couplings is necessary to separate between ggF and the other contribution (VBF/VH).

  -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.

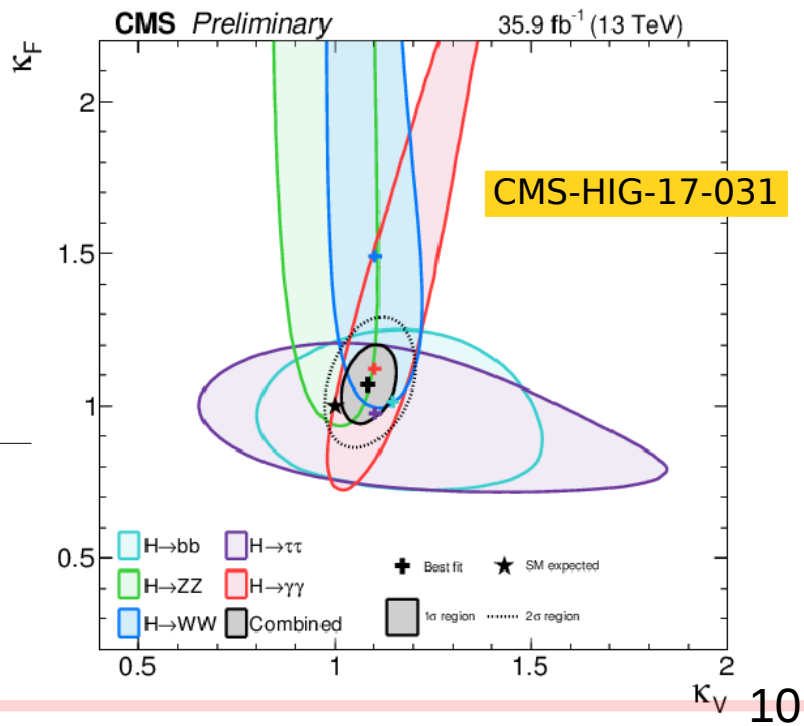



Likelihood scan as function of the signal strength




$\kappa_F$ ,and $\kappa_V$ coupling constants to fermions and bosons

**Combination with the other Higgs boson decay channel**




Crucial contribution in the Higgs combined coupling measurements

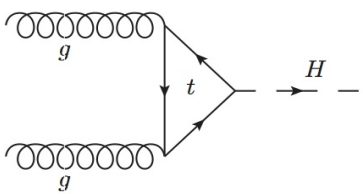
# Conclusion

- Studies on the Higgs boson properties are essential to understand the nature of the Higgs boson.
  - CMS results with $\mathcal{L}$= 35.9 $fb^{-1}$ for ggF, VBF and VH production mechanisms.
  - First observation of Higgs to WW (> 9σ)
  - Coupling measurements are in agreement with the SM prediction within 2σ.
- Stay tuned for other Higgs to WW results (i.e. high mass searches).

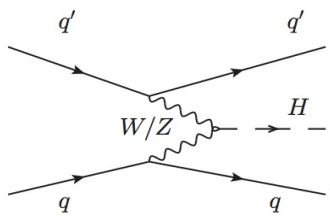
backup

# The Higgs boson in the Standard Model

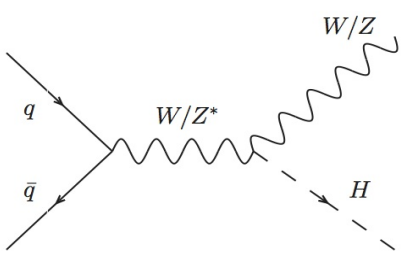
## Higgs boson production processes



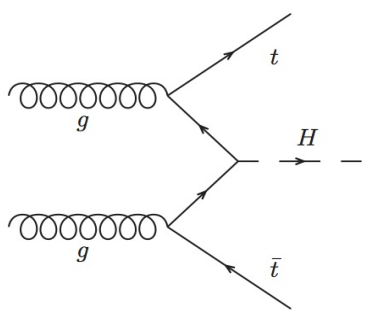

ggH 48.58 pb




qqH 3.78 pb



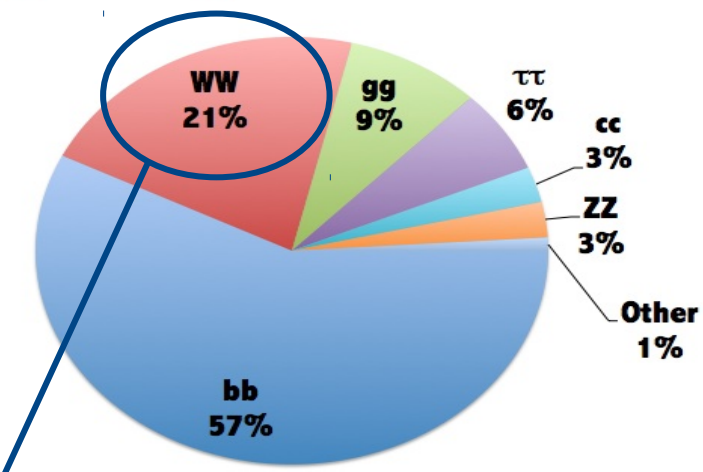

WH+ZH 2.38 pb




ttH+bbH 1.0 pb

xsec @ 13 TeV

## Higgs boson decays

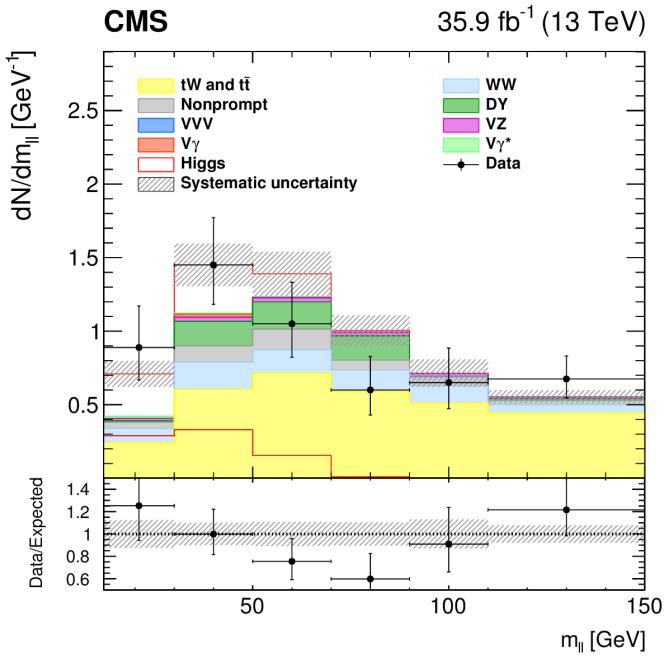



**WW** channel has the second largest **Branching Ratio** and a reasonable level of irreducible background.

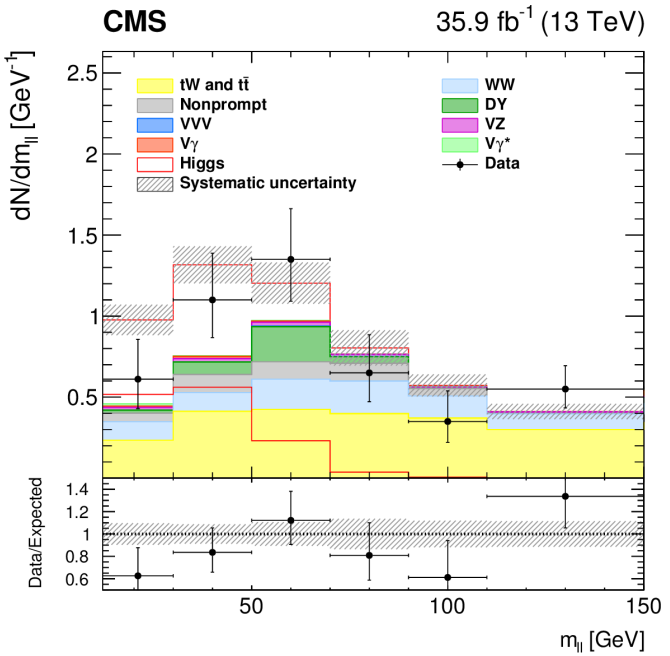
# Vector Boson Fusion, VH, WH and ZH categories

- **VBF**: characterized by pair of forward-backward jets. The analysis based is on m $\ell\ell$ distribution. Split in two region 400<mjj<700 GeV and mjj>700 GeV.

400<mjj<700 GeV

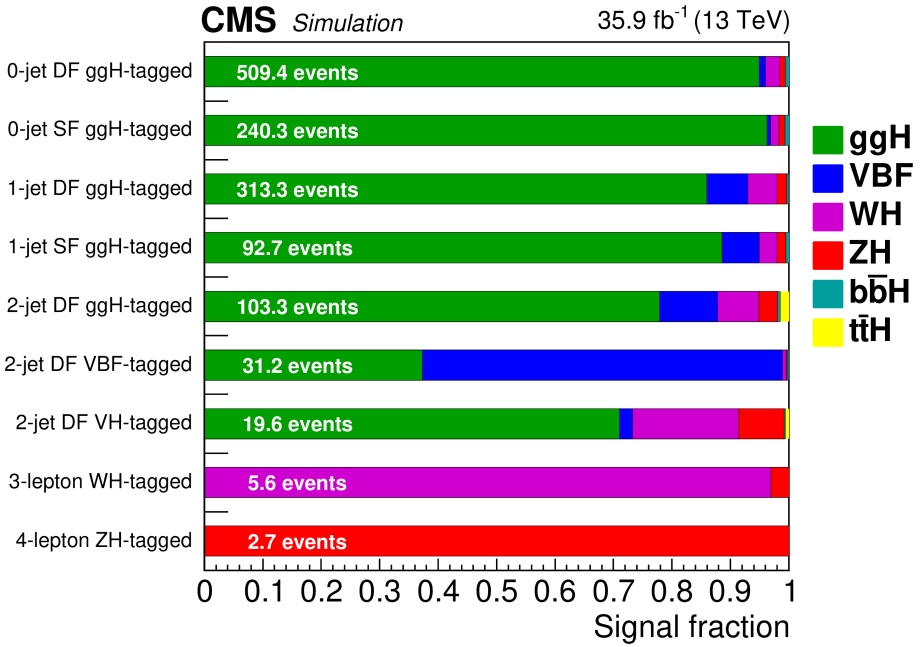


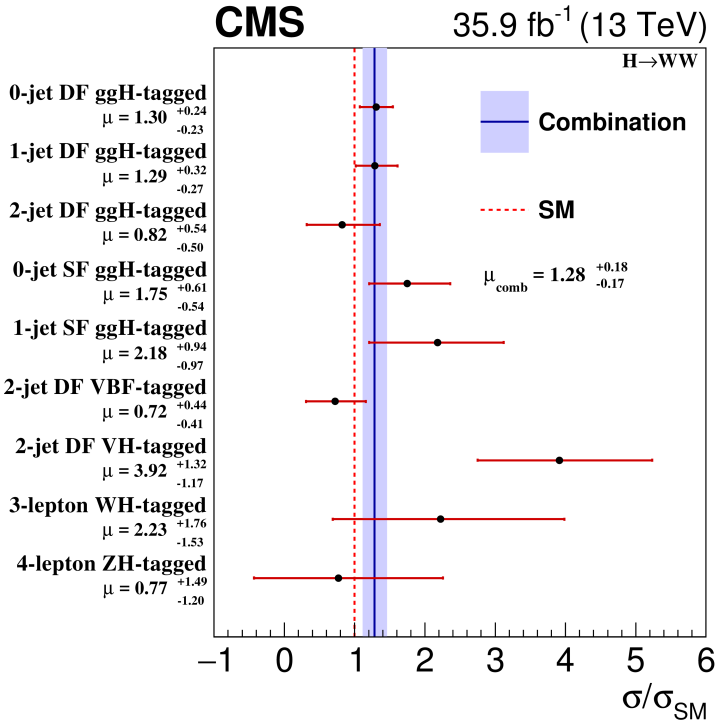

mjj>700 GeV



# Results III

- **Signal strengths and Significance in each categories**



# Results IV

- **Observed cross sections for the main Higgs boson production modes, normalized to the SM predictions**