Recent Higgs Boson Measurement in the WW Final State Using CMS data

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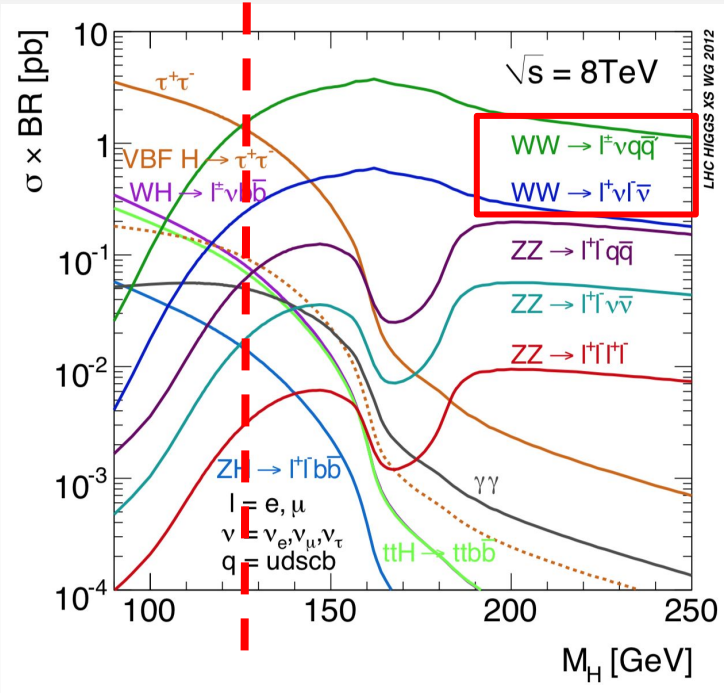
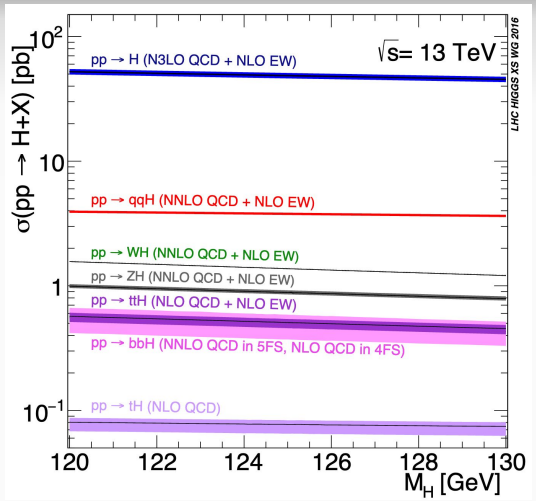
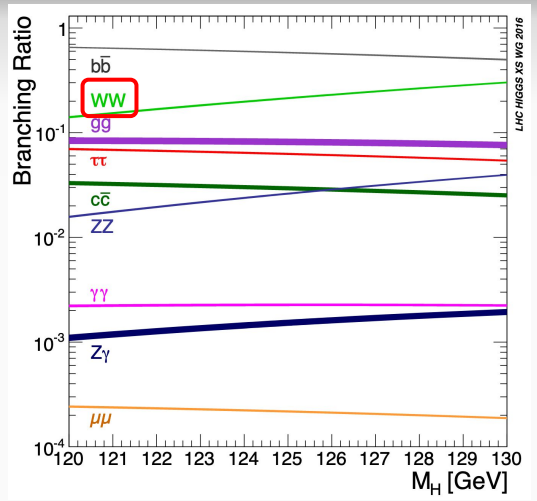
Introduction



- One of the many diverse LHC physics programme under RUN2 is measurement of the Higgs Boson properties.
- H→WW is an important channel for the measurement of the Higgs boson couplings and properties.
- In this talk:
  - Differential and integrated fiducial cross section measurement on leptonic H -> WW [CMS-PAS-HIG-19-002].
  - High mass Higgs boson search on X -> WW [CMS-HIG-17-033].

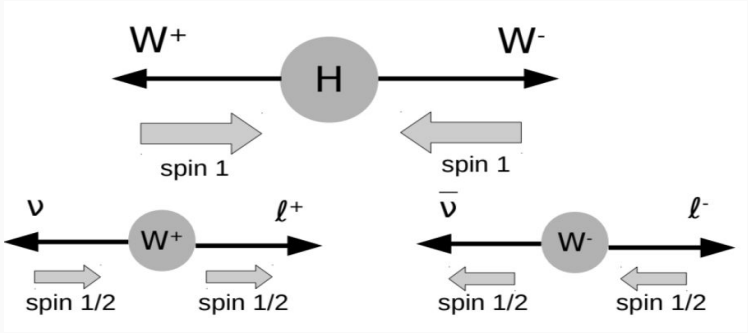
H -> WW -> 2l2v Channel





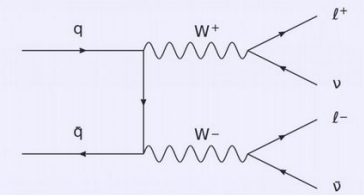
- Large signal yield and clean experimental signature.
- 2 opposite charge, isolated different flavour leptons, with moderate MET.
- The presence of two neutrinos hinder the reconstruction of Higgs boson mass.
- Good sensitivity to Higgs Coupling.

- W bosons emitted from spin-0 Higgs has opposite polarization.
- W couples only to left (right) handed fermion(anti-fermion).
- The 2 decayed leptons close in angle, and has smaller invariant mass.



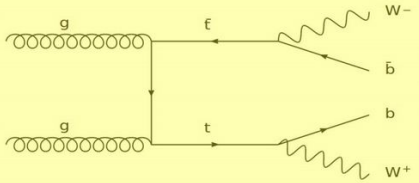
Main Backgrounds for H -> WW

Non-resonant WW



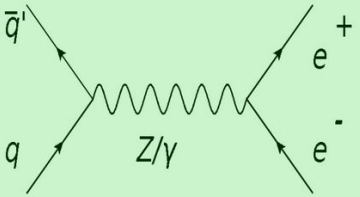
Same final state as the signal process.

$t\bar{t}$



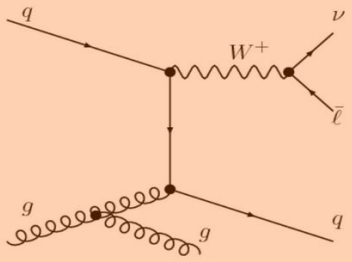
Very large cross section.
Same final state as the signal process + 2 b-jets.
Reduced vetoing b-jets

Drell-Yan



Very large in the same flavour final state.

Nonprompt

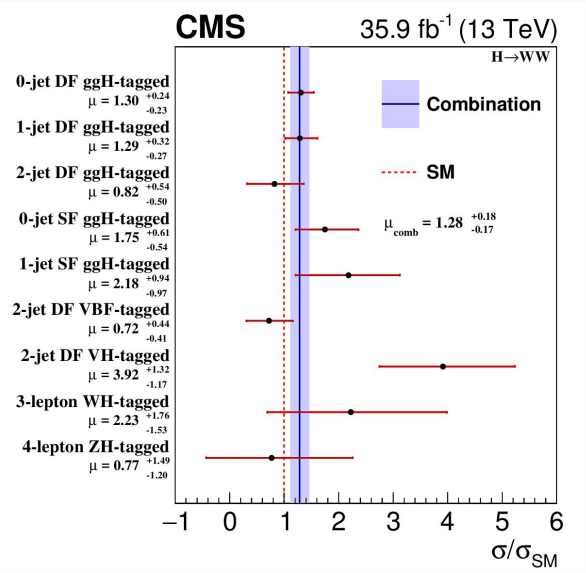


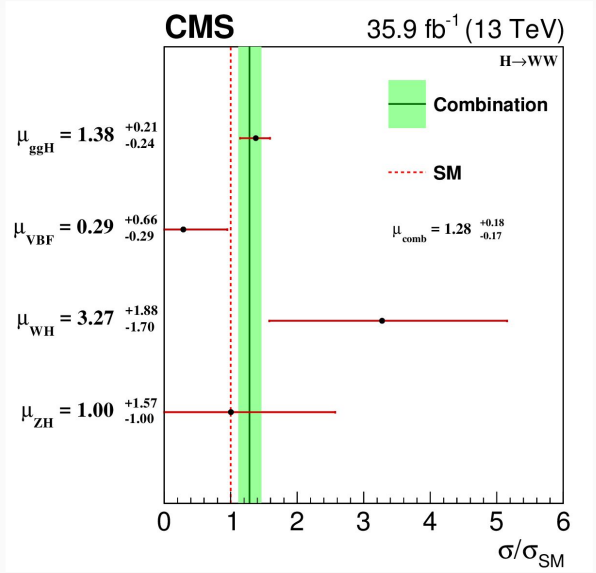
One jet can be misidentified as a lepton. Reduced with lepton ID and isolation.
Contribution also from semi-leptonic $t\bar{t}$.
Totally data-driven with fake rate method.

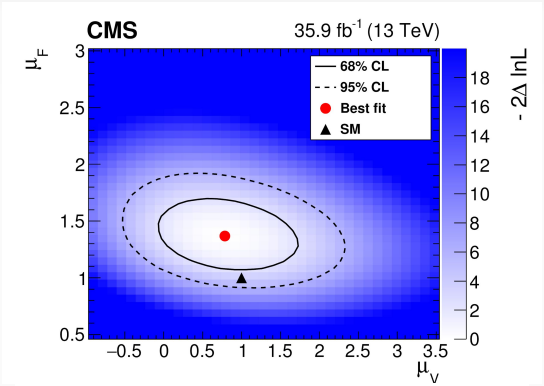
- ttbar and Drell-Yan background normalization taken from data using dedicated control regions.
- WW background normalization free-floating in the fit.

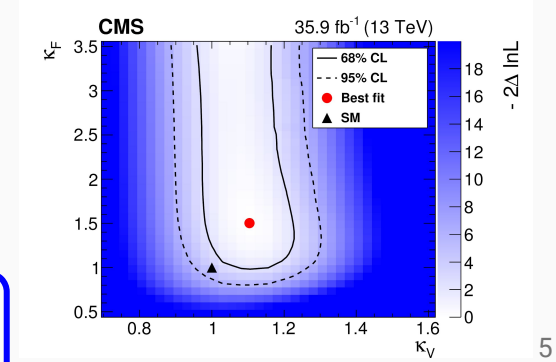
H -> WW -> 2l2v Channel at Run2

- Signal strength was measured by simultaneous likelihood fit on all signal and background regions.
- Observed(expected) significance of $9.1\sigma(7.1\sigma)$ are reported.





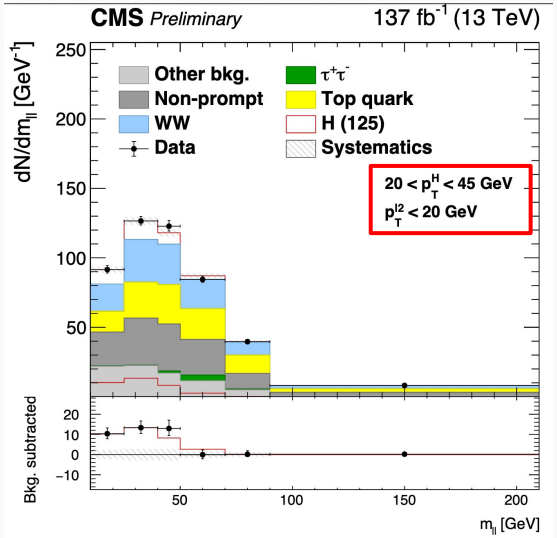


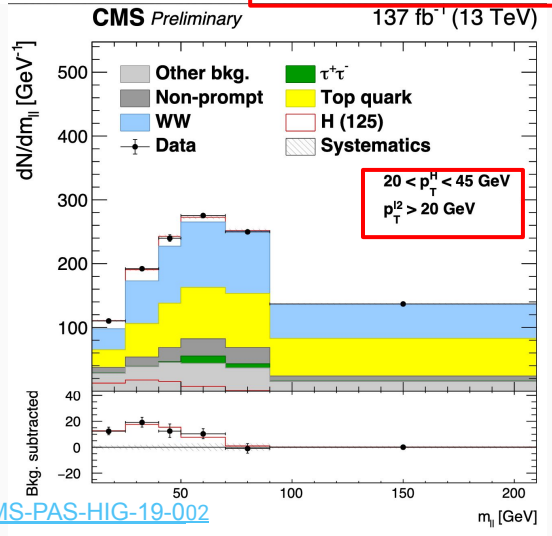


First H -> WW observation on Run2 2016 CMS dataset !!

Measurement of Higgs Differential Cross Section

Selection	Requirements	Note
	leading two leptons have opposite sign and different flavour,	
Preselection	$p_T^{\ell_1} > 25\,\text{GeV}$, $p_T^{\ell_2} > 13\,\text{GeV}$, $\lvert\eta\rvert < 2.5\ (2.4)$ for e (μ), $p_T^{\text{miss}} > 20\,\text{GeV}$, $p_T^{\ell\ell} > 30\,\text{GeV}$, no additional leptons with $p_T > 10\,\text{GeV}$	$m_T^{\ell_2} = \sqrt{2p_T^{\ell_2}p_T^{\text{miss}}\left[1-\cos\Delta\phi(\vec{p}_T^{\,\ell_2},\vec{p}_T^{\,\text{miss}})\right]}$ $m_T^{\text{H}} = \sqrt{2p_T^{\ell\ell}p_T^{\text{miss}}\left[1-\cos\Delta\phi(\vec{p}_T^{\,\ell\ell},\vec{p}_T^{\,\text{miss}})\right]}$
Signal region	$m^{\ell\ell} > 12\,\text{GeV}$, $m_T^{\text{H}} > 60\,\text{GeV}$, $m_T^{\ell_2} > 30\,\text{GeV}$, no b-tagged jets with $p_T > 20\,\text{GeV}$	Binned by p_T^{H} or N_{jet} and categorized by lepton properties

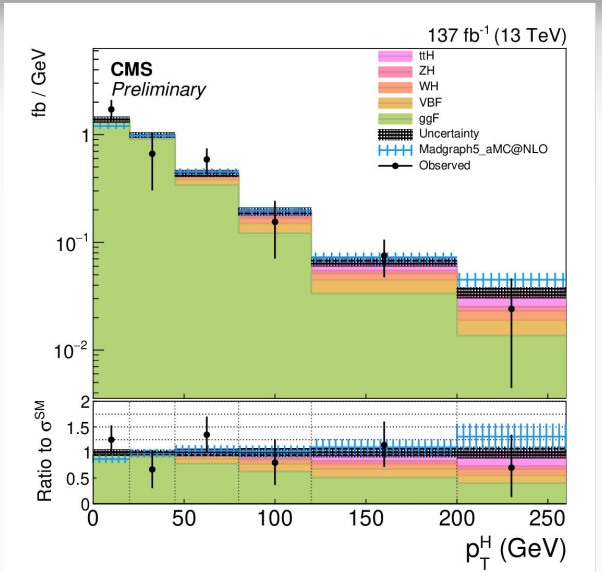


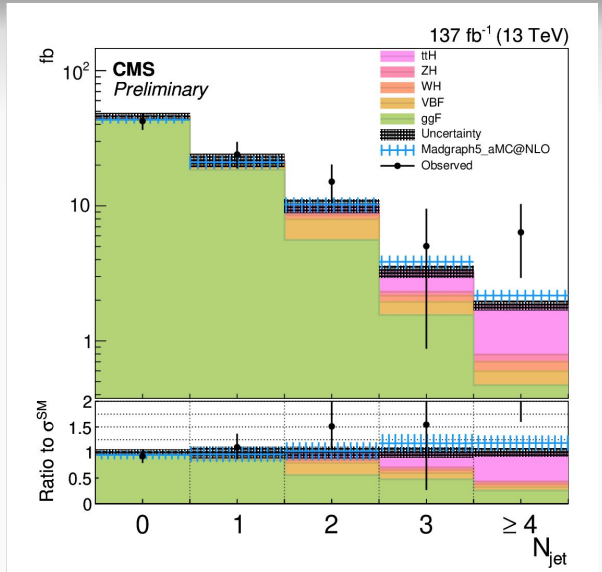


CMS-PAS-HIG-19-002

- Precision measurement of Higgs production cross section w.r.t differential basis observables.
- Sensitive to possible Yukawa coupling deviation.
- Dominant backgrounds: W^+W^-, ttbar, tau$^+$ tau$^-$.
- Further categorization within bin to optimize signal sensitivity.
- Signal events were extracted from the fit to 2D (m^{ll},m^{H}_{T}) distribution.

Differential Measurement Results





CMS-PAS-HIG-19-002

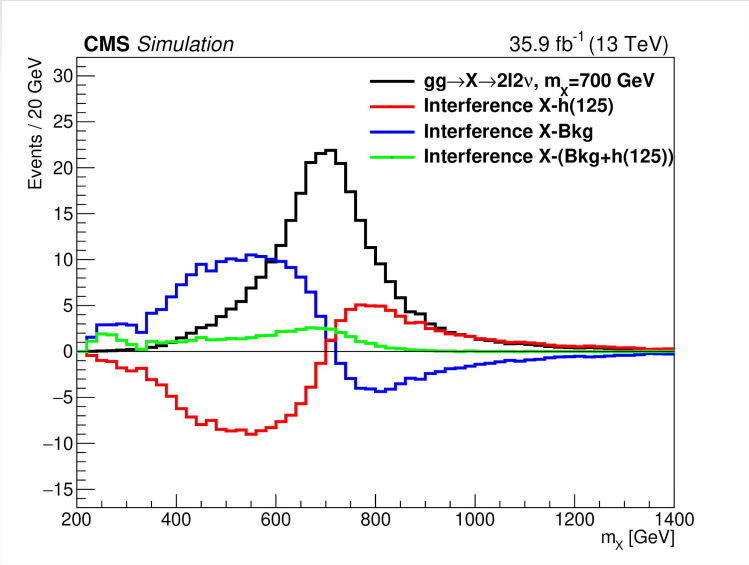
$$\mu^{fid} = 1.03^{+0.12}_{-0.11}(^{+0.05}_{-0.05}(stat.)^{+0.08}_{-0.07}(theo.)^{+0.03}_{-0.03}(lumi.)^{+0.07}_{-0.07}(exp.))$$
$$\sigma^{fid} = 85.0^{+9.9}_{-9.3}\ \text{fb.}$$

First H -> WW result on full Run2 CMS dataset!

- Scale factor on the signal template extracted from the fit in generator-level bins interpreted as signal strength.
- Cross sections are determined from the simultaneous fit over all bins, categories and control regions.
- Unfolding, regularization and signal extraction done in the fit.
- Alternative signal model consistent with observation.
- Main systematics: Non-prompt background, WW background, residual MET uncertainties, Lepton efficiency scale factors.

BSM High Mass Higgs Search

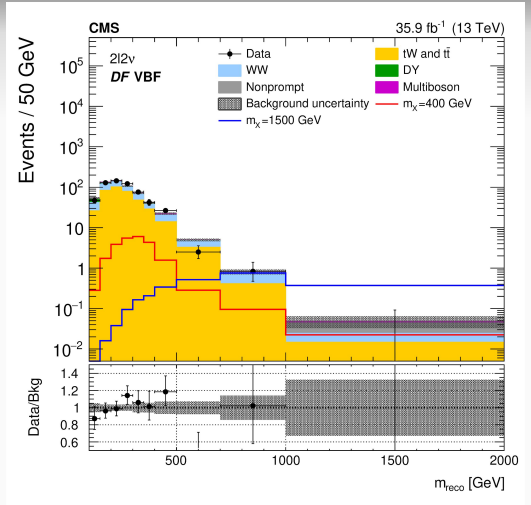
- WW channel is one of the sensitive channel for BSM search on Higgs mass > 200 GeV.
- BSM search performs on:
  - SM-like coupling heavy Higgs boson model.
  - 2HDM (tanβ-M_H):
    - Type-1: all quark couples to same Higgs doublet.
    - Type-2: u,d quark couples to different Higgs doublet.
  - MSSM:
    - M^{mod+}_{H}
    - hMSSM
- Event categorized to optimize signal sensitivity for ggF and VBF production mode.

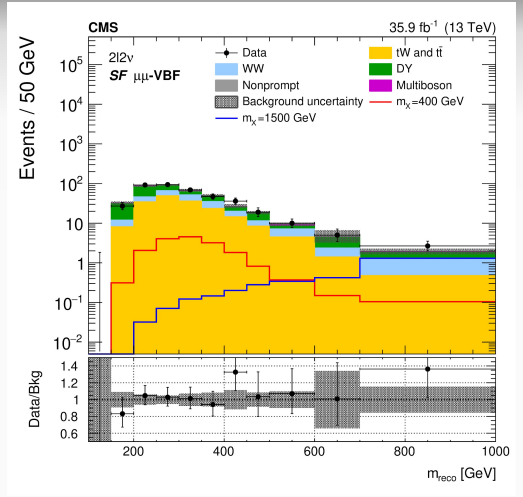


The signal model include simulation on differentiate high mass Higgs X interferes with WW continuum and SM Higgs off-shell tail.

High Mass X -> WW -> 2l2v

- Categorization by lepton flavour and number of associated jets.
- Well identified and isolated leptons to reduce non-prompt backgrounds.
- Vetoing btag to reduce top backgrounds.
- Reduces Electroweak backgrounds by vetoing third lepton.
- SF is limited by DY backgrounds.
- VBF tagged by exactly 2 AK4 jets, with 2 forward jet.
- Main backgrounds WW and top with floating normalization.





CMS-HIG-17-033

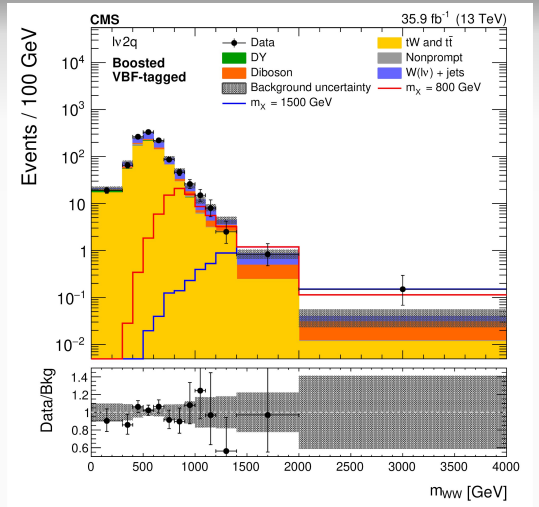
- p^{l1}_T> 25 GeV; p^{l2}_T> 20 GeV
- 0j, 1j , 2j , 2j VBF x e^+u^-
- MET > 20 GeV
- m_{ll} > 50 GeV
- p^{ll}_T > 30 GeV ; m^H_T> 60 GeV

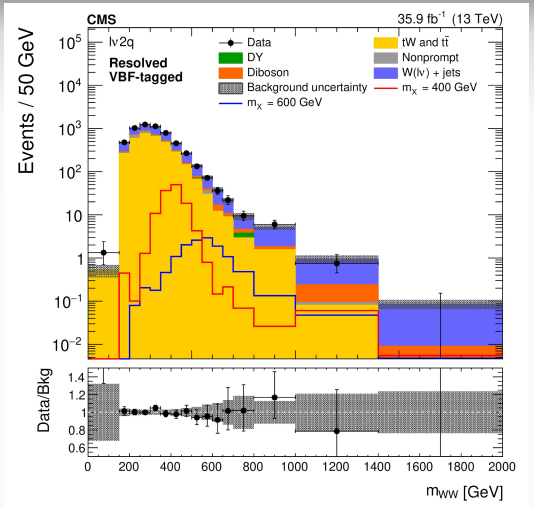
- p^{l1}_T> 20 GeV; p^{l2}_T> 20 GeV
- 2j VBF x e^+e^-/u^+u^-
- MET > 50 GeV
- m_{ll} > 120 GeV
- m^l_T > 100 GeV

$$m_T^I = \sqrt{(p_{\ell\ell} + E_T^{\text{miss}})^2 - (\vec{p}_{\ell\ell} + \vec{p}_T^{\text{miss}})^2}.$$

High Mass X -> WW -> lv2q

- Categorization by tagging of ggF and VBF production mechanism.
- Same background reduction with fully-leptonic signal region.
- VBF tagged by exactly 2 AK4 jets; ggF-tag (VBF-fail, MELA>0.5); untagged (ggF-fail).
- Jet substructure technique used to reconstruct merged jet, discriminate W boson decay from QCD jets.
- Main backgrounds W+jets and top both with floating normalization.





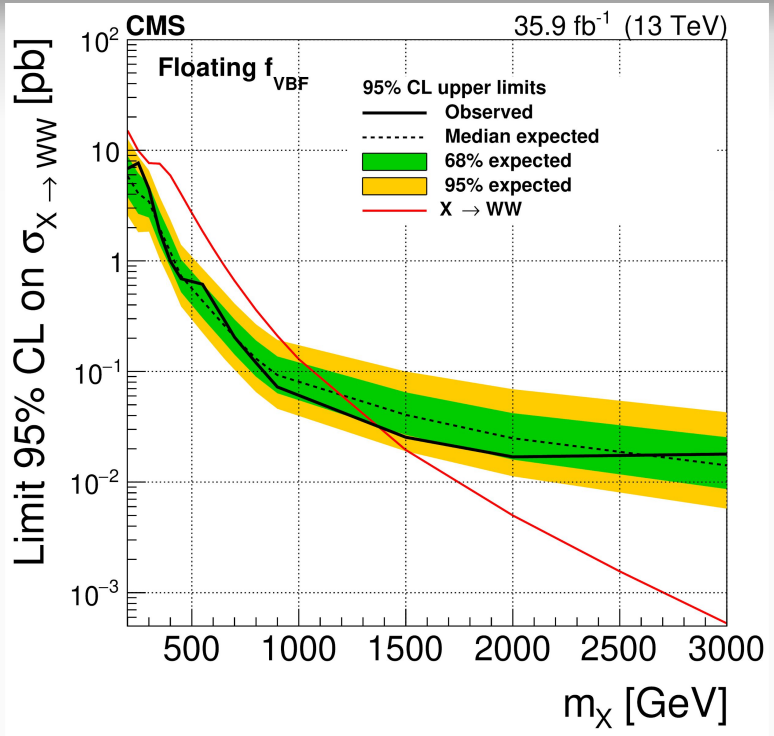
CMS-HIG-17-033

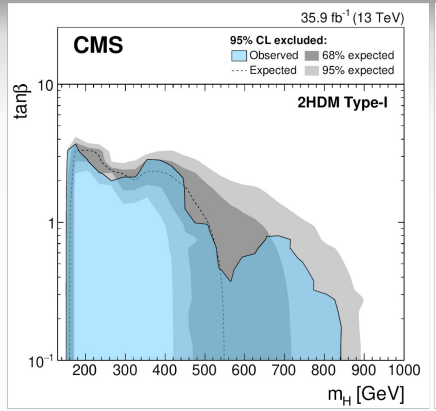
- p^l_T> 30 GeV, |eta| < 2.1(2.5)
- VBF, ggF, ggF-fail-tagged
- MET > 40 GeV
- 65 < m_J < 105 GeV
- p^T_w / m_{ww} > 0.4

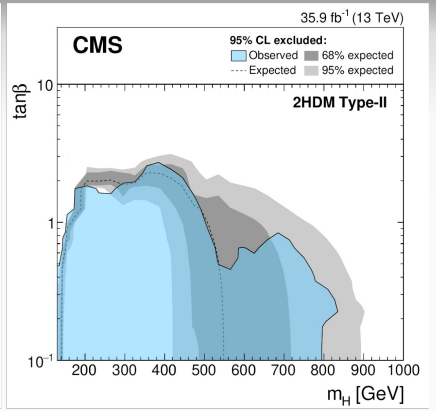
- p^l_T> 30 GeV, |eta| < 2.1(2.5)
- VBF, ggF, ggF-fail-tagged
- MET > 30 GeV
- 65 < m_{jj} < 105 GeV
- m^W_T >50 GeV; m^H_T>60 GeV
- p^T_w / m_{ww} > 0.35

m_{ww} = m(lv) + m(qq)

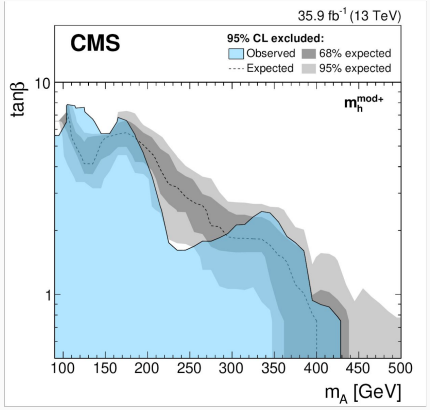
High Mass Higgs Search Limit

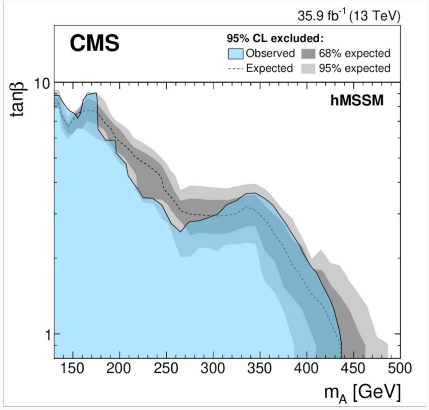






CMS-HIG-17-033





Limits set on production cross section for different VBF fractions, tanβ-m_H in 2HDM models, and tanβ-m_A in hMSSM

Conclusion

- H -> WW channel is the promising channel on Higgs measurement and coupling study.
- New limits have been set on a SM-like heavy Higgs boson, 2HDM's and hMSSM's scenarios on 2016 Run2 CMS datasets.
- Differential and fiducial cross section measurement on H -> WW channel were presented based on full Run2 CMS datasets, after the first H -> WW observation.

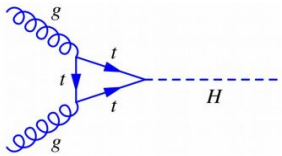
$$\mu^{fid} = 1.03^{+0.12}_{-0.11}\left(^{+0.05}_{-0.05}(stat.)\,^{+0.08}_{-0.07}(theo.)\,^{+0.03}_{-0.03}(lumi.)\,^{+0.07}_{-0.07}(exp.)\right)$$

$$\sigma^{fid} = 85.0^{+9.9}_{-9.3}\ \text{fb.}$$

Backup

Higgs Boson Production at LHC

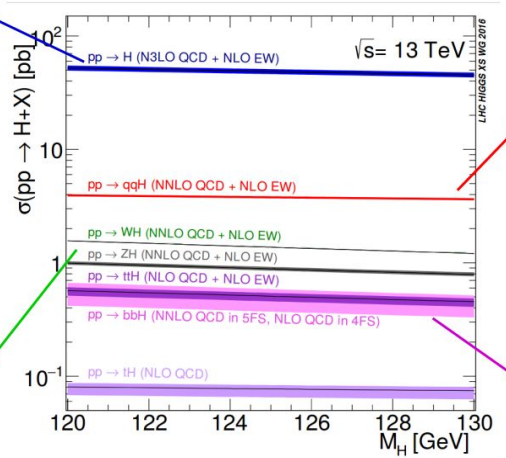
Enough statistics to tackle all the main production modes.



Gluon fusion (ggH)

- Sensitive to Higgs couplings with fermions (t, b quarks).

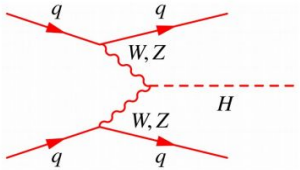
$\sigma \times \mathcal{B}(\mathrm{H} \to \mathrm{WW}) = 9.5$ pb



Vector boson fusion (VBF)

- Sensitive to the coupling with W and Z.

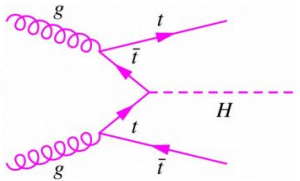
$\sigma \times \mathcal{B}(\mathrm{H} \to \mathrm{WW}) = 0.8$ pb

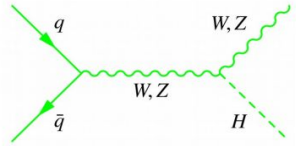


Top associated production (ttH)

- Sensitive to the direct coupling with top quark.

$\sigma \times \mathcal{B}(\mathrm{H} \to \mathrm{WW}) = 0.1$ pb





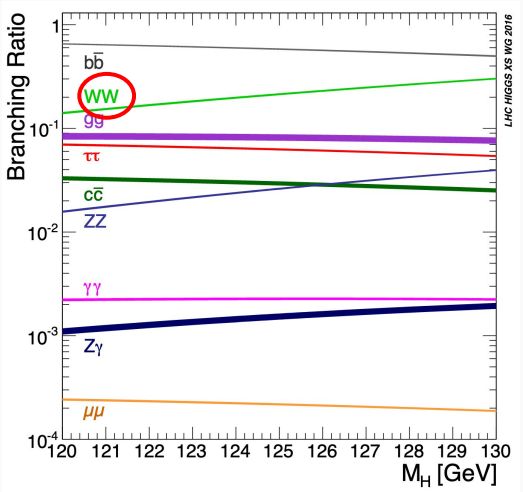
Vector boson associated prod. (VH)

- Sensitive to the coupling with W and Z.

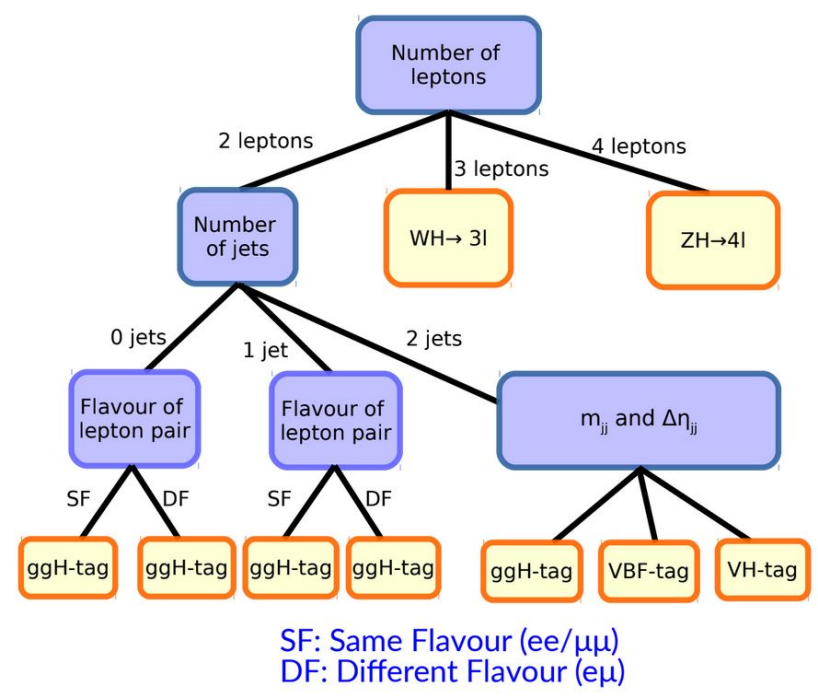
$\sigma \times \mathcal{B}(\mathrm{H} \to \mathrm{WW}) = 0.5$ pb

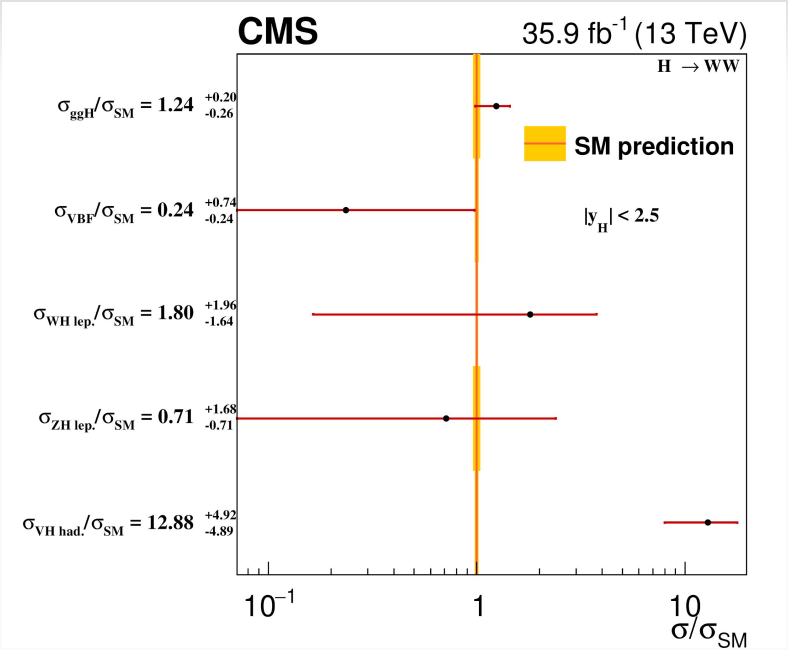
Expected total number of H -> WW events on full Run2 datasets:

10.9 pb x 137,000 pb-1 = 1.5 million of H -> WW's events



Inclusive WW Measurement





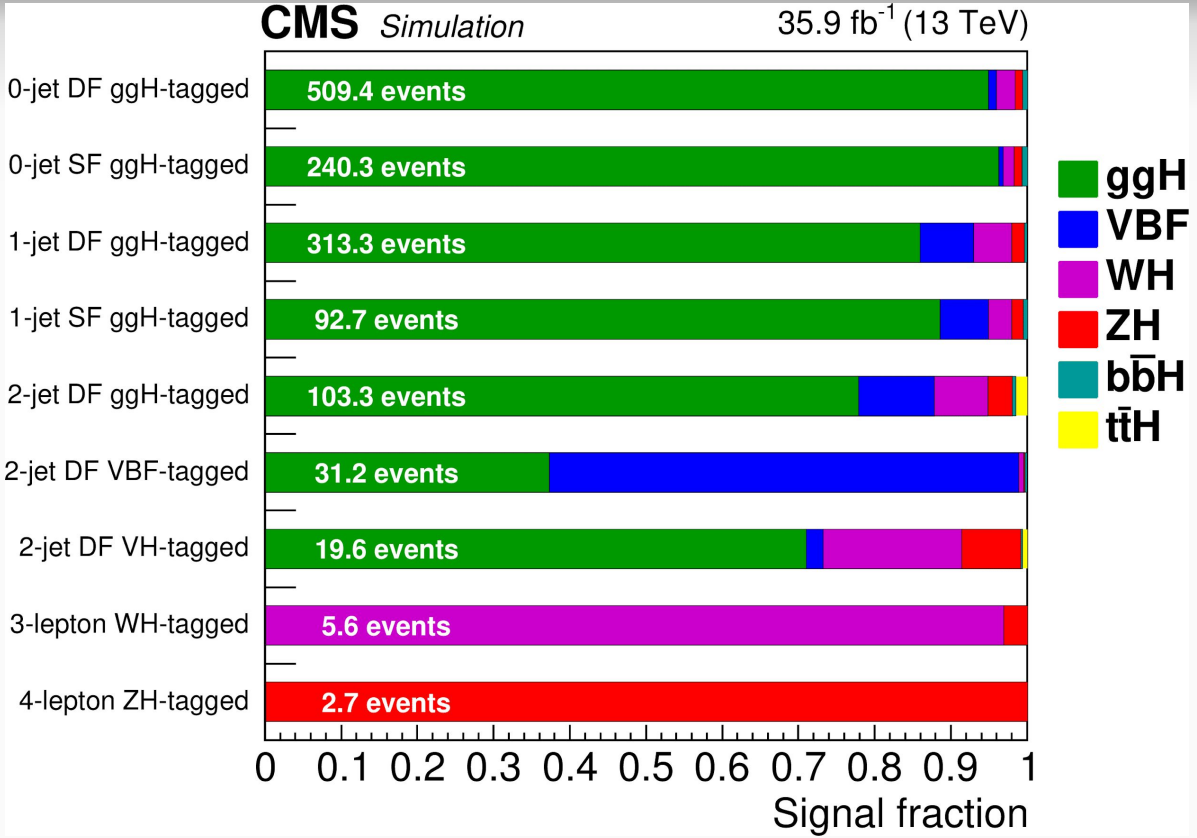
Events are categorized according to lepton composition and jets to tag production mode.

CMS-HIG-16-042

First H -> WW observation on 35.9 fb^{-1} CMS dataset

Significance: $9.1\sigma(7.1\sigma)$

Inclusive HWW signal fraction



CMS-HIG-16-042

Fiducial phase space and fit

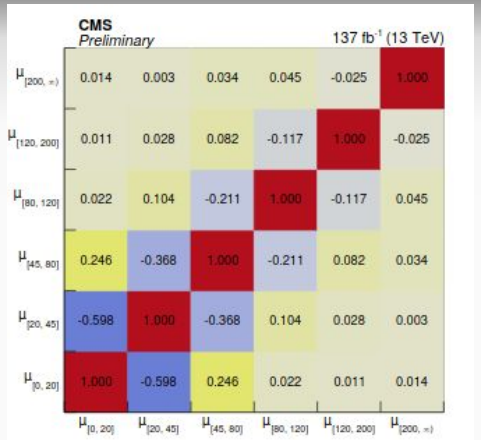
Fiducial and none-fiducial parameters are scaled in each signal events . The fiducial modi is extracted from each gen-level bins by the regularized fit.

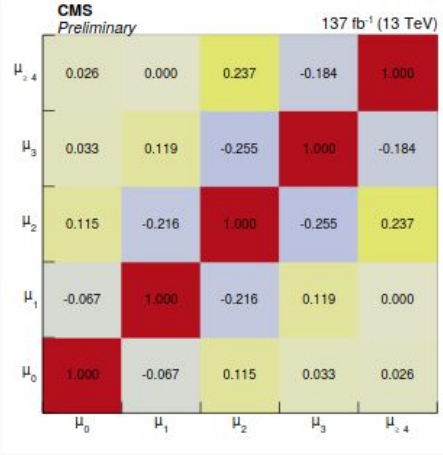
$$\sigma^{SM} = 82.5 \pm 4.2 fb$$

CMS-PAS-HIG-19-002

Lepton origin	Direct decay product of $H \to WW$
Lepton flavor and charge	Different flavor, opposite charge
Leading lepton p_T	$p_T^{\ell_1} > 25\,\text{GeV}$
Trailing lepton p_T	$p_T^{\ell_2} > 13\,\text{GeV}$
Pseudorapidity of the leptons	$\lvert\eta\rvert < 2.5$
Dilepton mass	$m^{\ell\ell} > 12\,\text{GeV}$
Dilepton transverse momentum	$p_T^{\ell\ell} > 30\,\text{GeV}$
Transverse mass of trailing lepton	$m_T^{\ell_2} > 30\,\text{GeV}$
Higgs transverse mass	$m_T^{H} > 60\,\text{GeV}$

Fiducial phase space definition

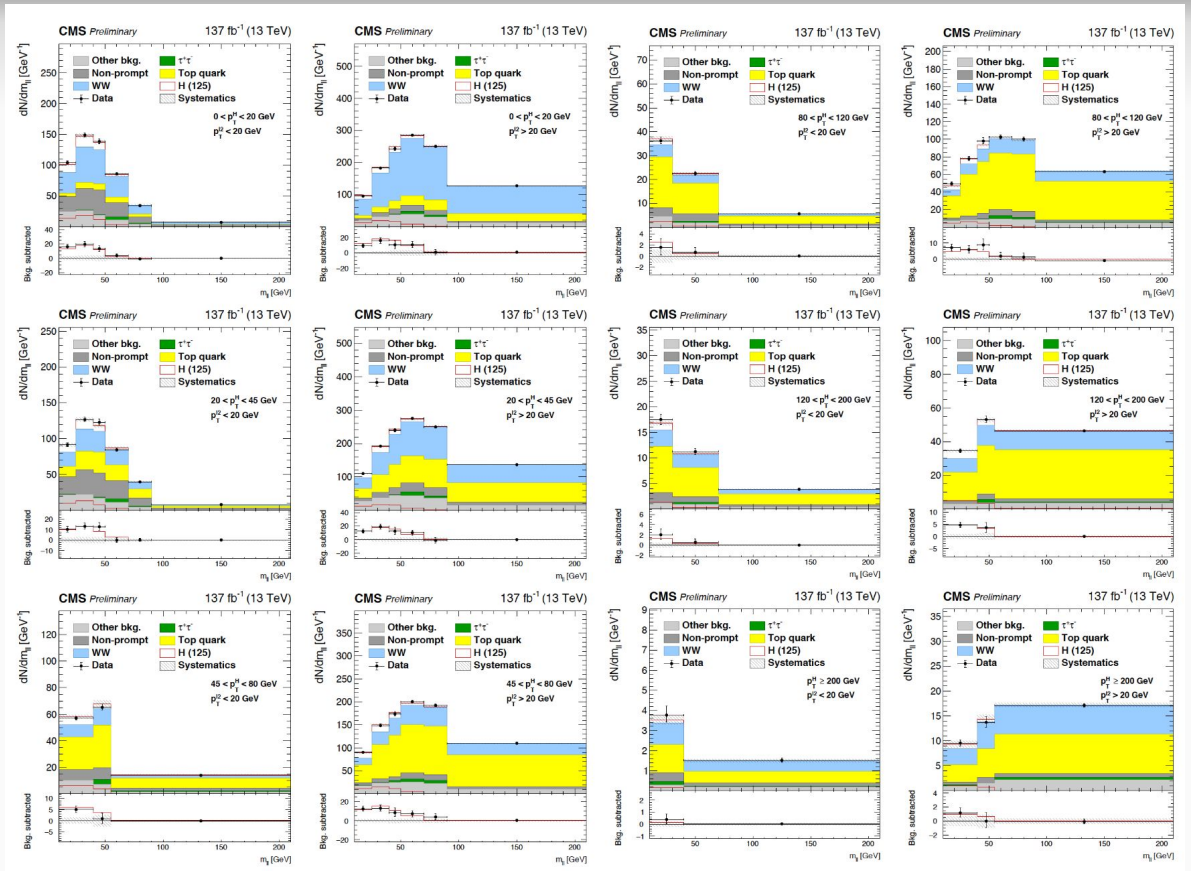




Differential Cross Section Events Selection

Selection	Requirements	Note
Preselection	leading two leptons have opposite sign and different flavour, $p_T^{\ell_1} > 25\,\text{GeV}$, $p_T^{\ell_2} > 13\,\text{GeV}$, $\lvert\eta\rvert < 2.5$ (2.4) for e (μ), $p_T^{\text{miss}} > 20\,\text{GeV}$, $p_T^{\ell\ell} > 30\,\text{GeV}$, no additional leptons with $p_T > 10\,\text{GeV}$	
Signal region	$m^{\ell\ell} > 12\,\text{GeV}$, $m_T^H > 60\,\text{GeV}$, $m_T^{\ell_2} > 30\,\text{GeV}$, no b-tagged jets with $p_T > 20\,\text{GeV}$	Binned by p_T^H or N_{jet} and categorized by lepton properties
$t\bar{t}$ control region	$m^{\ell\ell} > 50\,\text{GeV}$, $m_T^{\ell_2} > 30\,\text{GeV}$, at least one b-tagged jet with $p_T > 20\,\text{GeV}$ if $N_{\text{jet}} = 0$, else $p_T > 30\,\text{GeV}$	Binned by p_T^H or N_{jet}
$\tau^+\tau^-$ control region	$40 < m^{\ell\ell} < 80\,\text{GeV}$, $m_T^H < 60\,\text{GeV}$, no b-tagged jets with $p_T > 20\,\text{GeV}$	Binned by p_T^H or N_{jet}

Postfit mll for mll bin



Postfit M_{ll} distribution per P^{H}_{T} bin.

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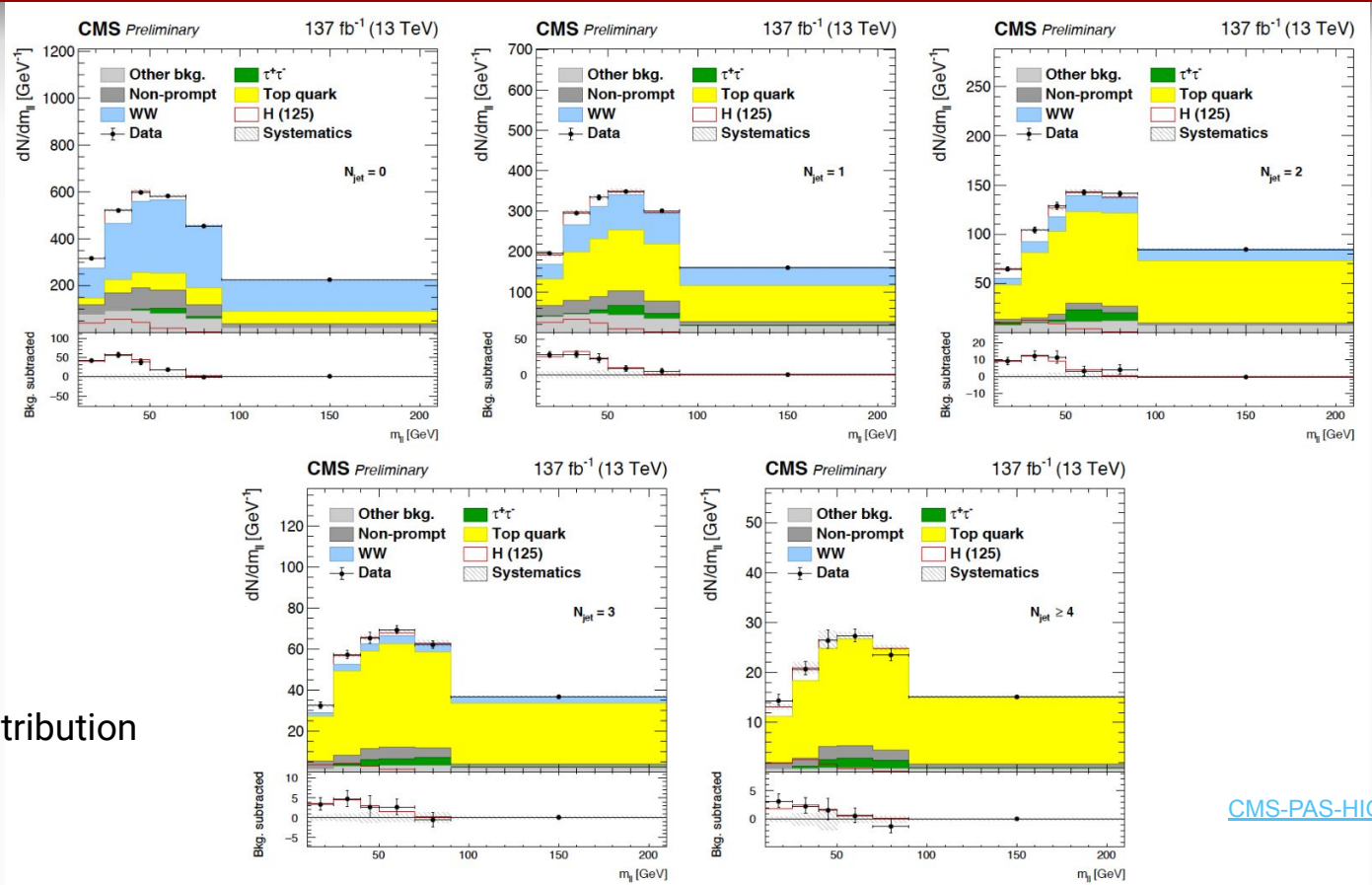
Postfit mll for Jet bin



Postfit M_{ll} distribution per N_{jet} bin.

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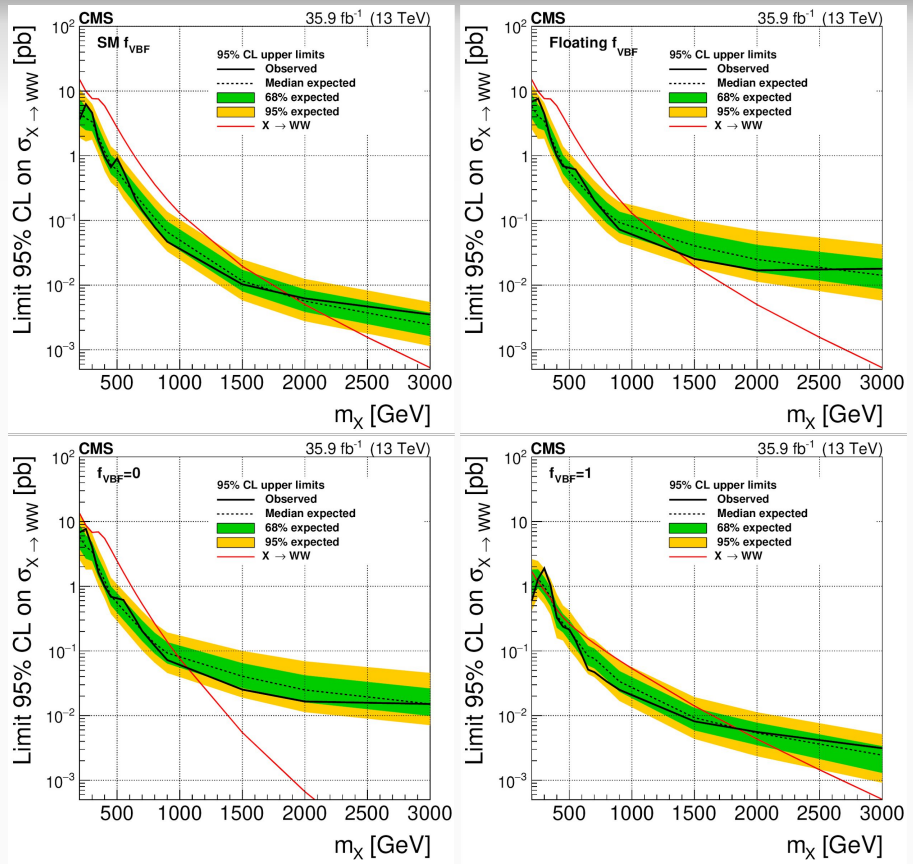
fVBF fraction

$$f_{VBF} = \frac{\sigma^{VBF}}{\sigma^{tot}}$$



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