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on behalf of the CMS collaboration
Università di Siena & INFN di Firenze

Results on Higgs to WW with the CMS detector at 13 TeV

"Lake Louise 2017: Lake Louise Winter Institute 2017"
19-26 Feb. 2017, University of Alberta, Lake Louise (Canada)

Outline

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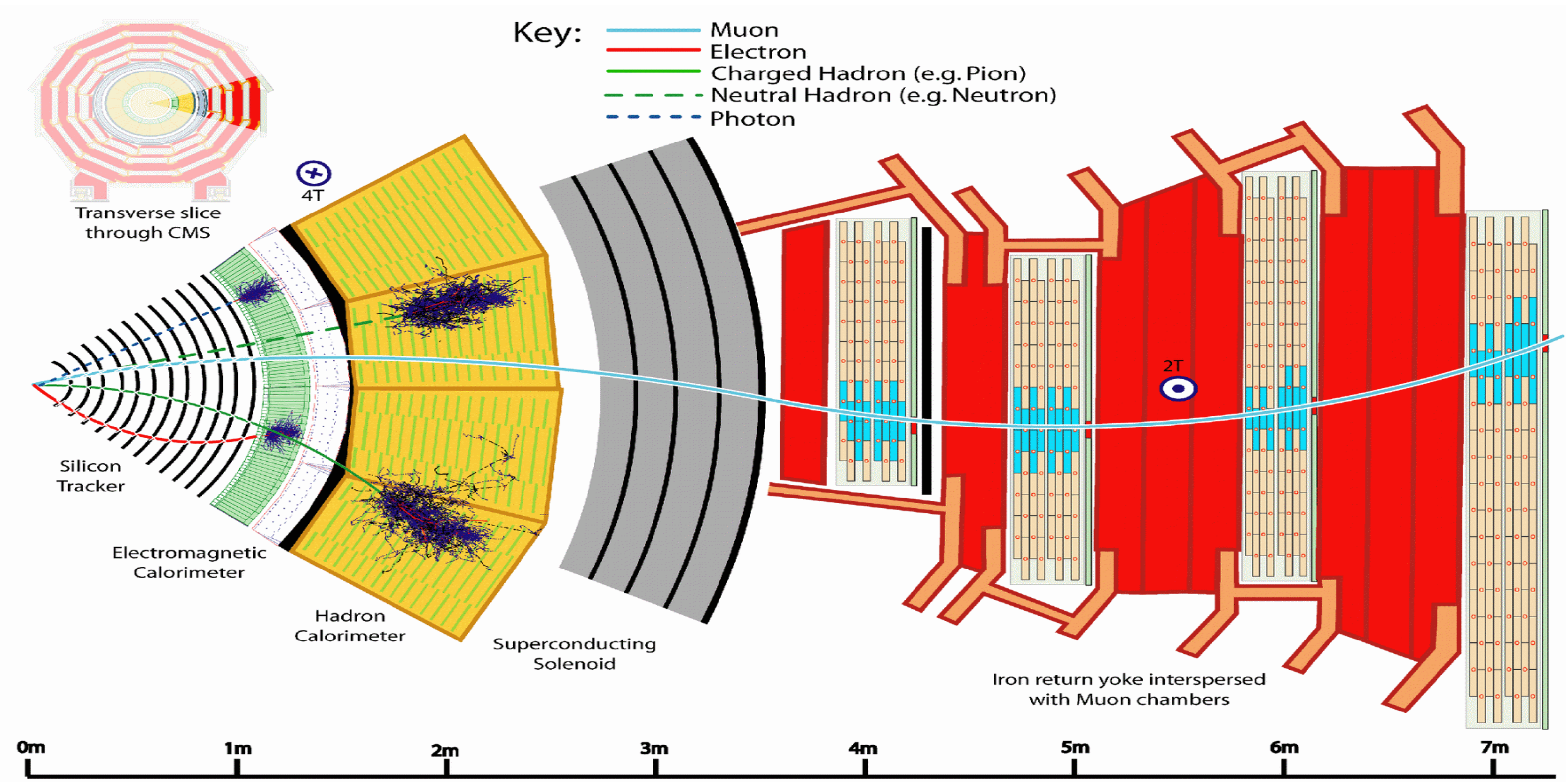
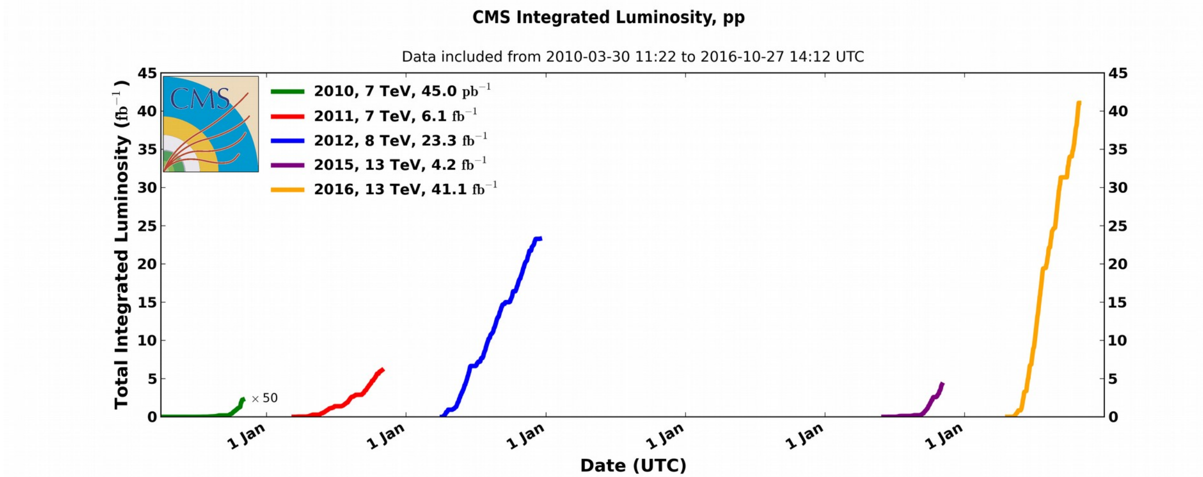
- **Analysis H → WW → $2\ell 2\upsilon$ Standard Model Higgs**

- **High mass analysis, X → WW → $2\ell 2\upsilon$, in range 200-1000 GeV**

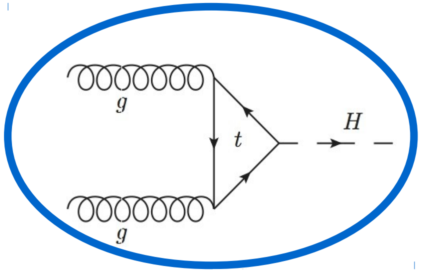
The CMS detector

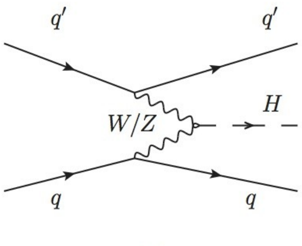




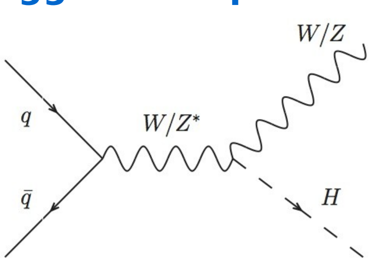
The Higgs boson in the Standard Model

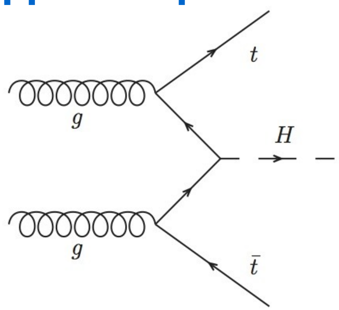
Higgs boson production processes





ggH 48.58 pb **qqH 3.78 pb**

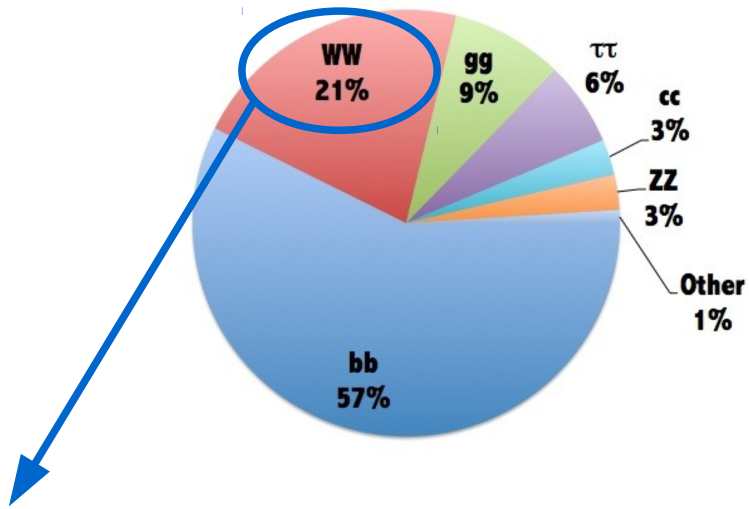




WH+ZH 2.38 pb **ttH+bbH 1.0 pb**

xsec @ 13 TeV

Higgs boson decays



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

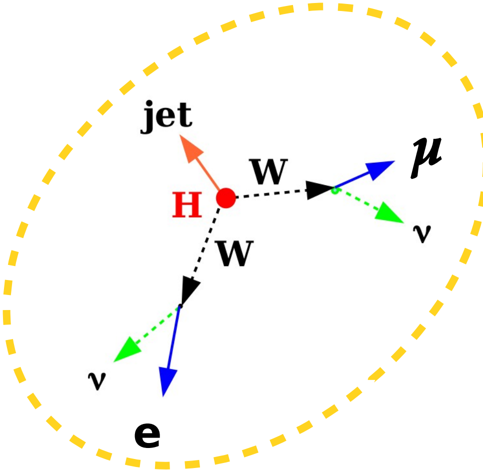
CMS-PAS-HIG-15-003

Analysis $H \rightarrow WW \rightarrow 2\ell 2\nu$

Only the dominant production mechanism, the **gluon fusion**, is targeted in this analysis. Final states in which the two W bosons decay **leptonically** are studied. The data sample correspond to a total integrated luminosity of **2.3 fb^{-1}** collected in 2015.

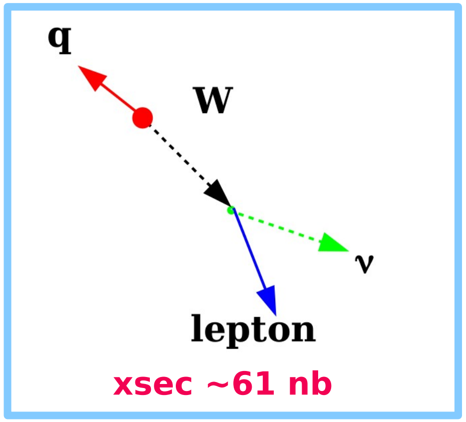
Signal and backgrounds

→ **Signal**: only eμ final state, including τ leptons decaying leptonically, is studied to suppress DY background. Extra jets in the final state arise only from initial state radiation.

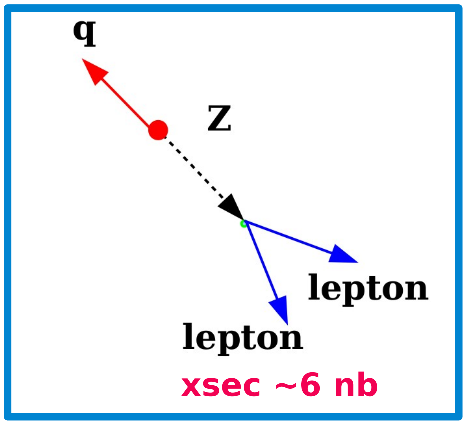


→ **Main backgrounds**: several processes can lead to the similar event properties.

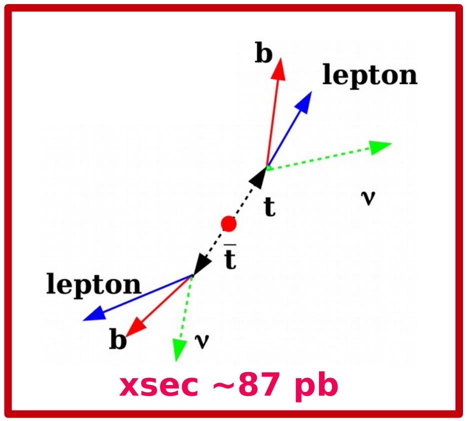
$W \rightarrow \ell\upsilon$ +jets



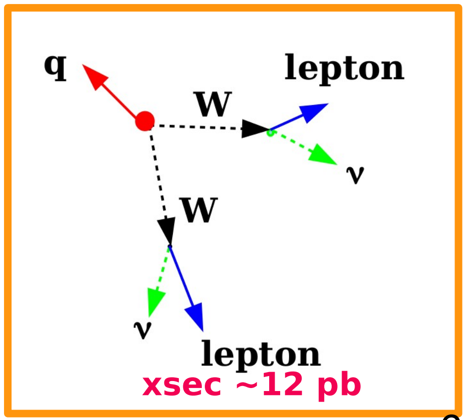
DY $\rightarrow \ell\ell$



tt$\rightarrow$WWbb$\rightarrow \ell\upsilon\ell\upsilon$bb



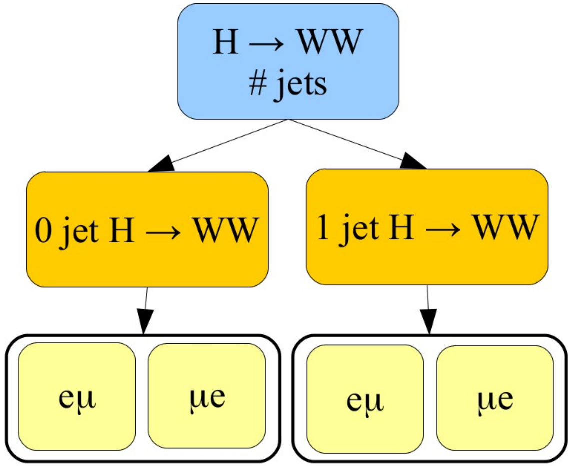
WW $\rightarrow \ell\upsilon\ell\upsilon$



Analysis strategy

→ To increase SM Higgs boson sensitivity, events are categorized as follow:

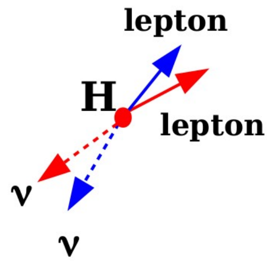
- **0 jet** → background dominated by non-resonant WW.
- **1 jet** → contribution from non-resonant WW and top background are of similar importance.
- eμ and μe p_T ordered leptons, to exploit different fake rate for e and μ.
- **Two jet** → Not studied



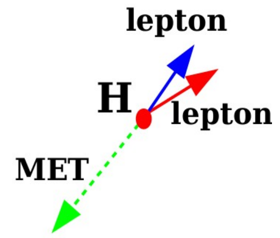
The **gluon fusion** is the dominant production process in jets categories.

Analysis strategy

→ The neutrinos in the final state escape direct detection and lead to large MET: impossible to reconstruct the Higgs invariant mass spectrum.



Final state in physics process



Final state inside CMS detector

→ In the transverse plane the momentum is conserved: di-leptons and MET system is considered to build a **transverse mass** variable:

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

Events selection

Triggers

→ **Single lepton** trigger: the thresholds on lepton p_T are 23(18) GeV for e(μ).

→ **Di-lepton** e(μ) trigger: minimum p_T 17(8) GeV for e(μ) case or 17(12) for μ(e) case.

→ Trigger **efficiency** for Single and di-lepton is 99%.

Baseline analysis selection

→ Exactly one electron and one muon with opposite charge.

→ leading lepton p_T>20 GeV, trailing lepton p_T>10(13) GeV for μ(e).

→ Well identified and isolated leptons to reject fake's leptons.

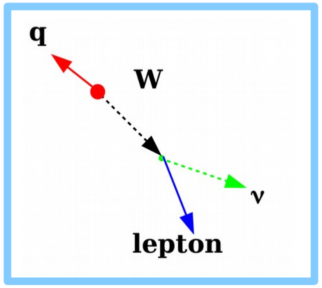
→ $m_{\ell\ell}$>12 GeV to remove QCD backgrounds.

Background suppression: W+jets (Fake)

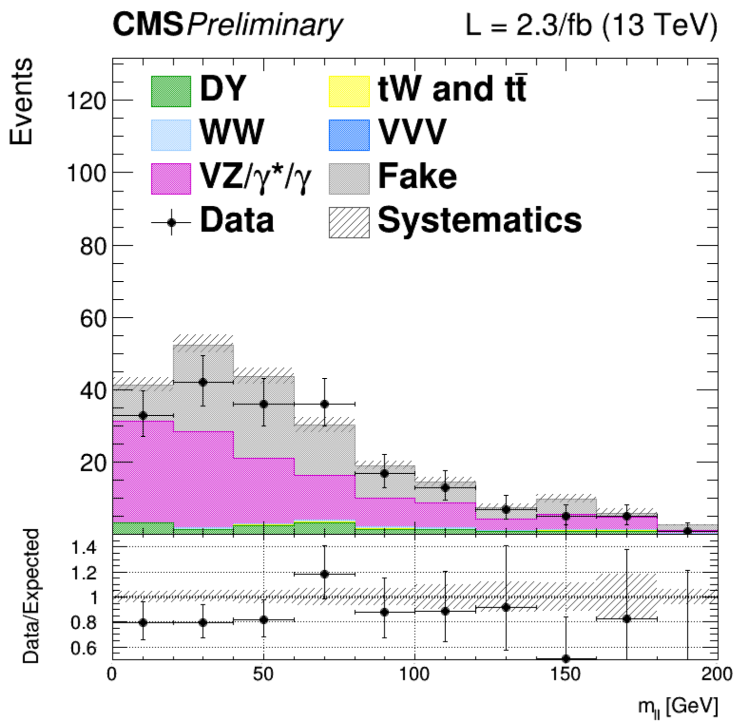
→ Real lepton and MET. The jet is identified wrongly as second lepton.

→ Reject by lepton isolation.

→ The probability for a jet to be reconstructed as a lepton is estimated on data.



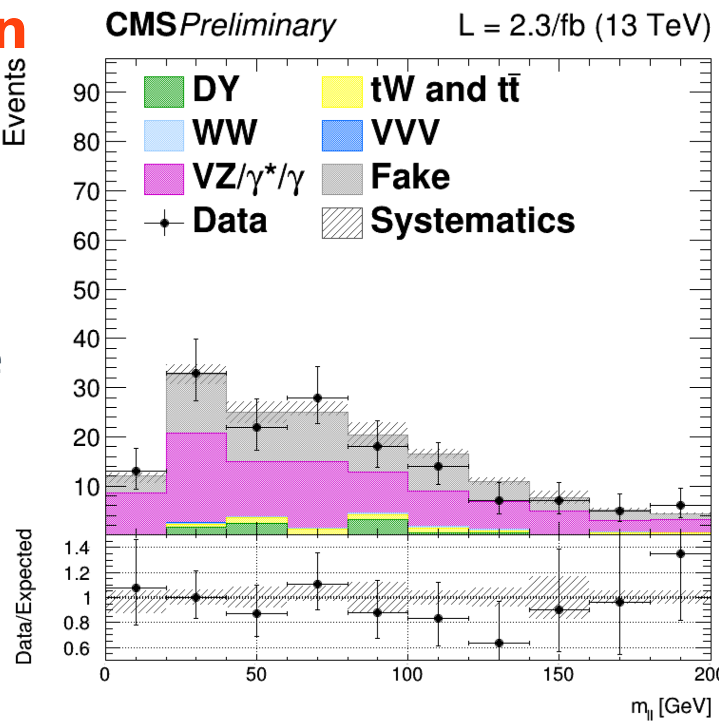
Control region



0-jet

→ Events passing the same selection.

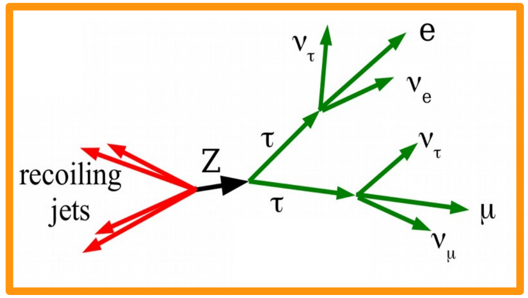
→ eμ pair with the **same charge.**



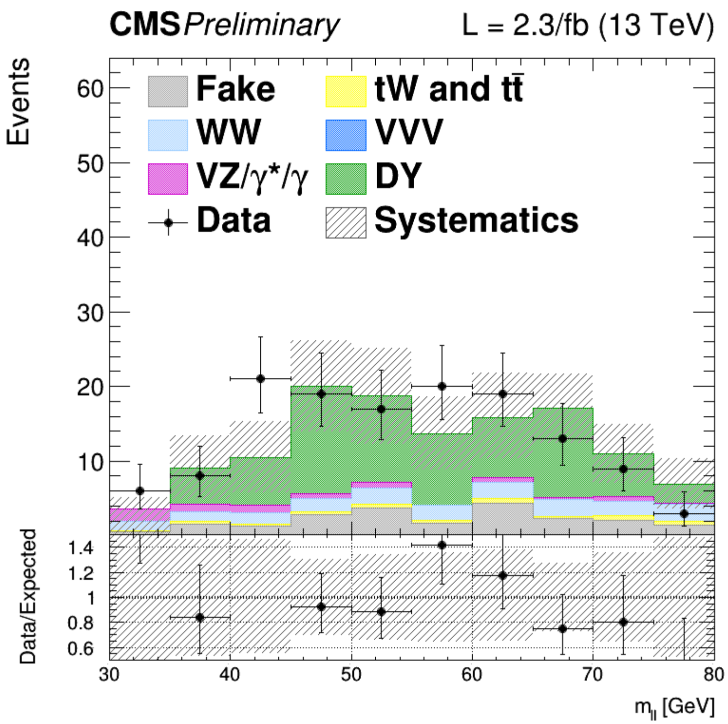
1-jet

Background suppression: DY

→ The DY→ττ→eμ, is dominant at **low m_T^H** .
Cuts to suppress: MET >20 GeV, $p_T^{\ell\ell}$ >30 GeV and m_T^H >60 GeV.



Control region

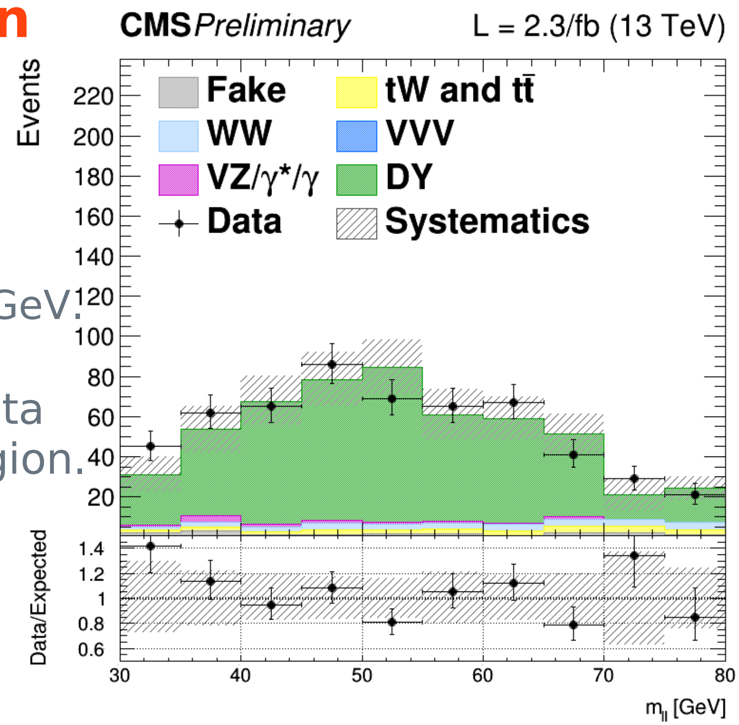


0-jet

→ Low m_T^H region, m_T^H < 60 GeV.

→ 30 GeV<$m_{\ell\ell}$< 80 GeV.

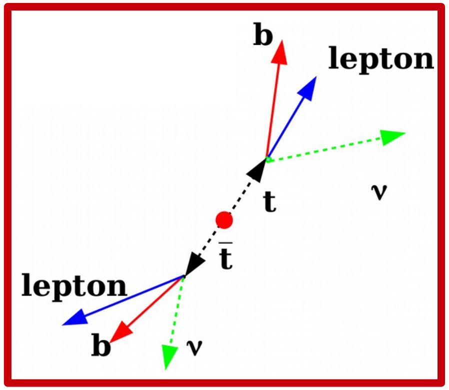
→ Normalized to data in the control region.



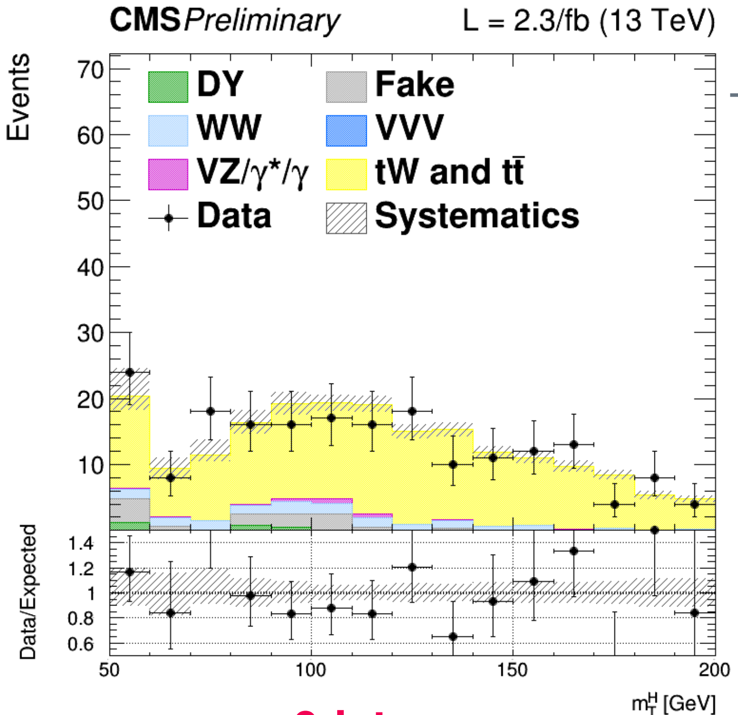
1-jet

Background suppression: Top

→ The Top background is characterized by b-jet: to reject this background **no b-tag** jets with p_T>20 GeV are required.



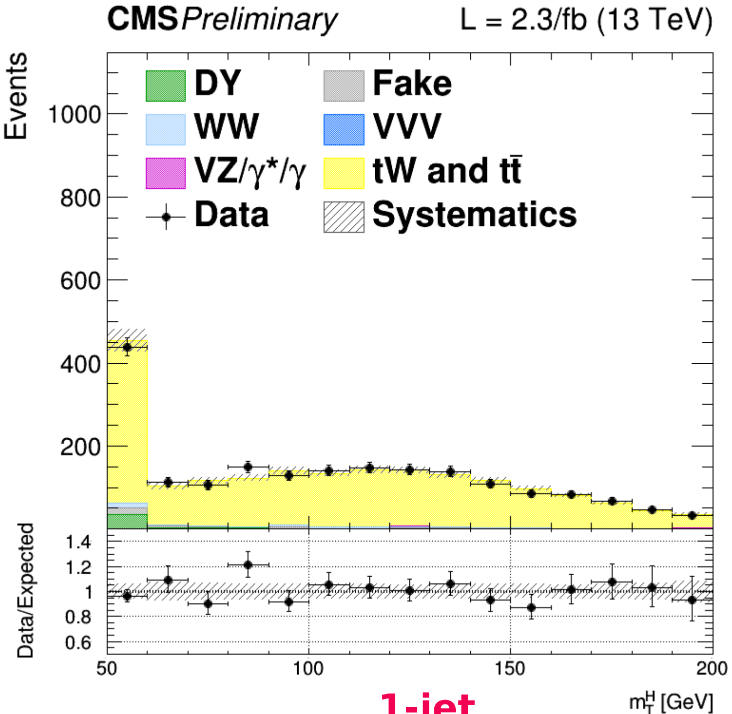
Control region: is used to normalize the simulation to the data in the region. This is then used to estimate top background in the signal region.



0-jet

→ Required at least a **b-tag jet** with:

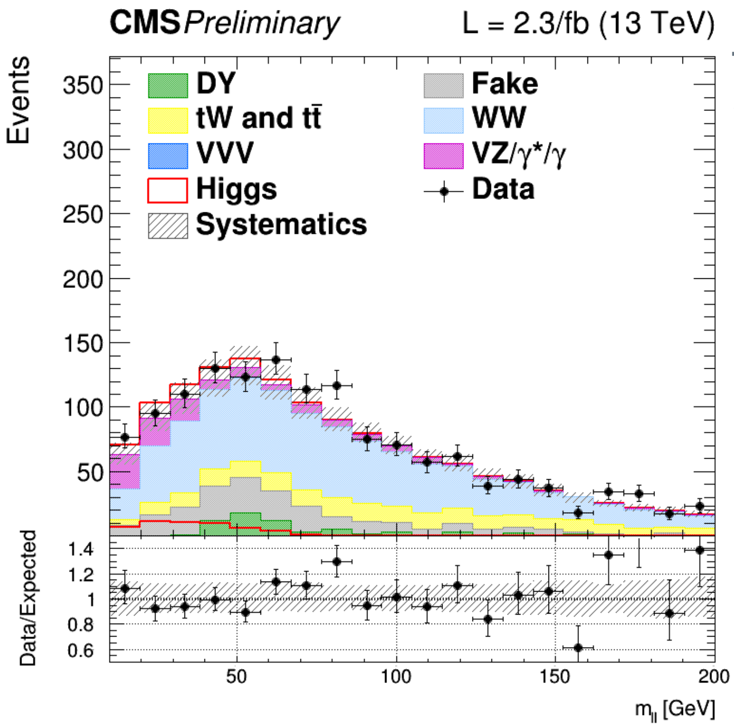
- 20<p_T<30 GeV for **0 jet**
- p_T>30 GeV for **1 jet**



1-jet

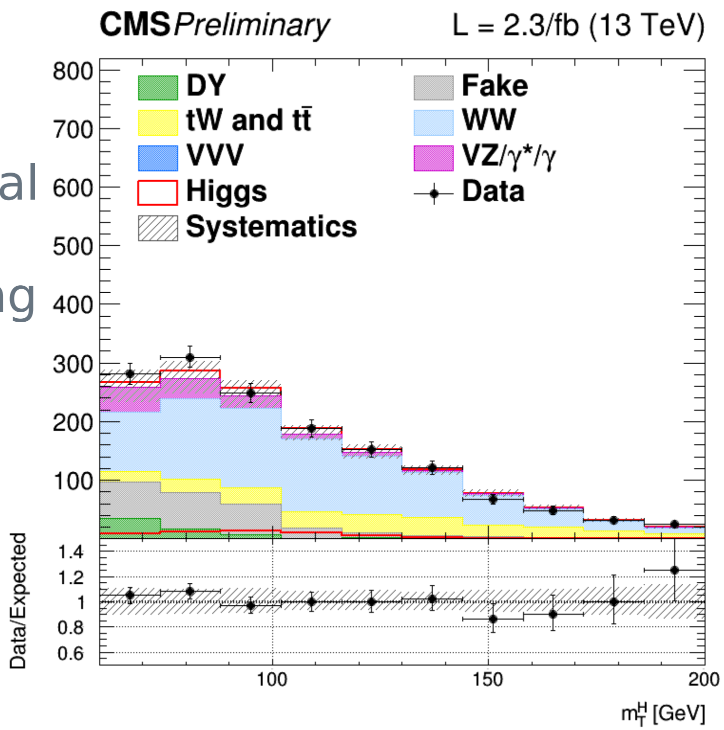
Signal and non-resonant WW

→ Non-resonant WW populates the entire phase space in $m_{\ell\ell}$ while the Higgs is concentrated at low value.
→ The shape is also different in m_T^H.



$m_{\ell\ell}$ 0-jet

The non-resonant WW is estimated directly in the signal region extraction procedure by letting it float freely to exploit these kinematic properties.



m_T^H 0-jet

Systematic uncertainties

Experimental uncertainties

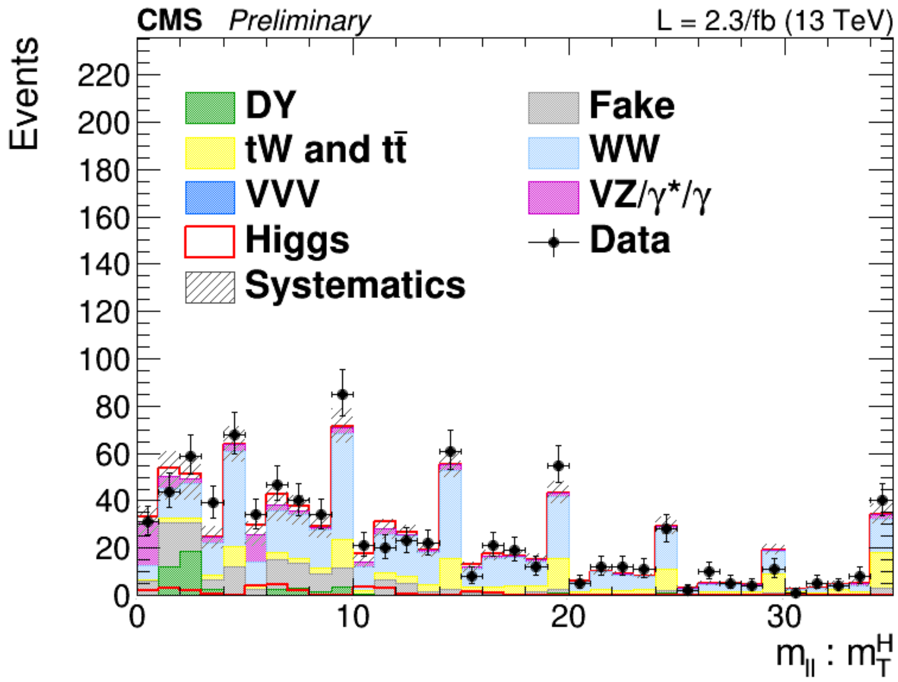
- Luminosity: **2.7%** at 13 TeV.
- Single and double trigger acceptance: **2%**.
- Lepton recontruction and identification efficiencies: **0.5-5%** for e and **0.5-1.7%** for μ depending on p_T e η.
- Jet energy scale: **1-11%** depending on p_T e η.
- MET resolution taken in account by propagating the corresponding uncertainties on lepton and jet.
- Scale factor for b-tag efficiency.

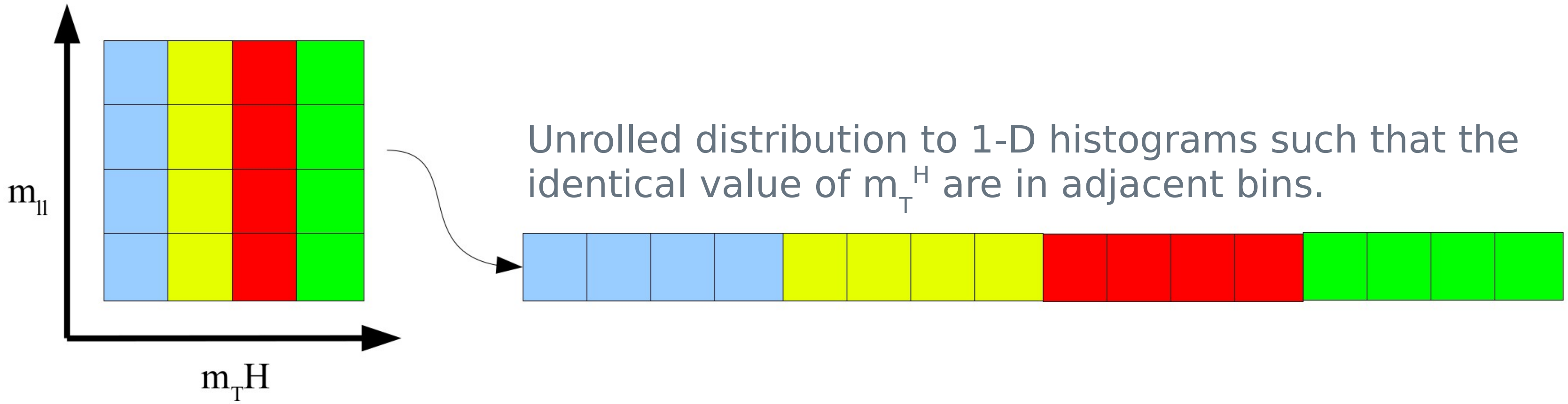
Theoretical uncertainties: assumed to be indipendent in the signal and background production rate.

- PDF and α_S, computed by LHC Higgs cross section working gruop.
- Underlying event uncertainty is estimated by comparing two different UE tunes, the effect is about 5% for UE tuning.
- Categorization on jet multiplicity are **5.6%** for 0-jet and **13%** 1-jet bin categories: Stewart-Tackmann.

Signal extraction

To extract the Higgs boson signal a binned fit is performed using 2-D distributions of $m_{\ell\ell}$ the and $\mathbf{m_T^H}$ for signal and all backgrounds processes in four categories.





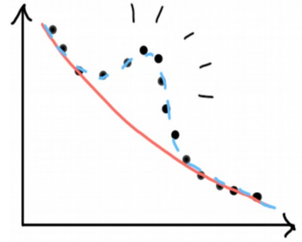
Unrolled distribution to 1-D histograms such that the identical value of m_T^H are in adjacent bins.

Significance=**0.7σ** (expected 2.0σ).
Signal strength: **σ/σ(SM)= 0.3 ± 0.5**

CMS-PAS-HIG-16-023

High mass

A search for spin 0 resonance in the $H \rightarrow WW \rightarrow 2\ell 2\upsilon$ channel is briefly described. The analysis is performed in a range of heavy scalar masses of $200 < M_X < 1000$ GeV. Similar selection criteria of $m_H = 125$ GeV analysis are applied.



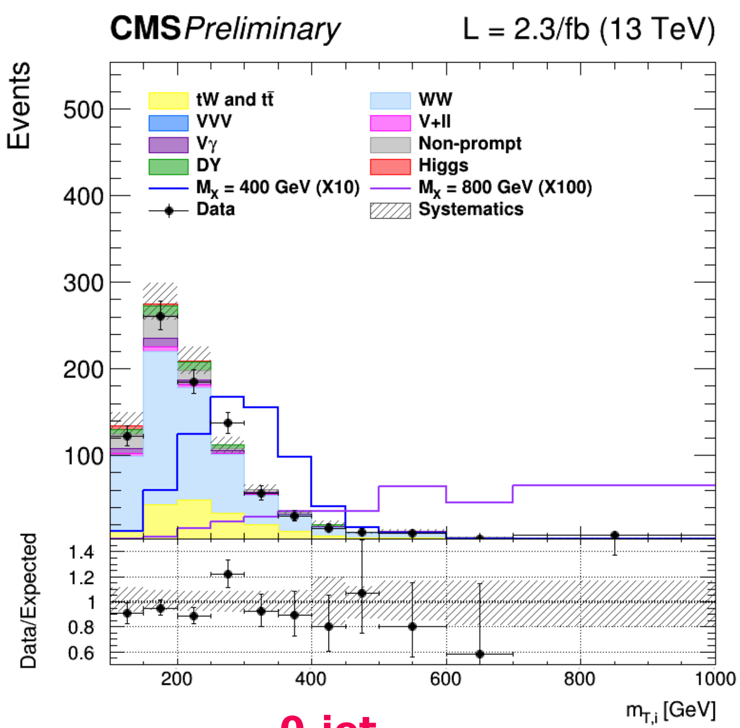
Improved transverse mass

The search has been carried out in the 0-jets, 1-jet and VBF categories in order to increase the signal sensitivity to the two different production mechanisms **gg** and **VBF**.

To discriminate signal and background an "**improved**" transverse mass $m_{T,i}$ (or "visible" mass) is defined.

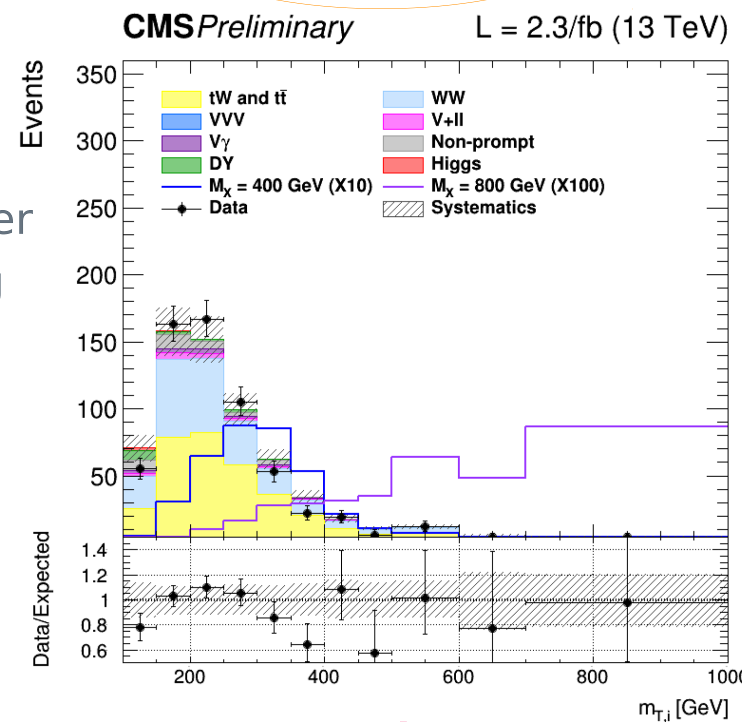
$$m_{\mathrm{T,i}} = \sqrt{(p_{ll} + E_{\mathrm{T}}^{\mathrm{miss}})^2 - (\vec{p}_{ll} + \vec{p}_{\mathrm{T}}^{\mathrm{miss}})^2}$$

Sum of the two four-momenta P^{μ}, E^{μ}



0-jet

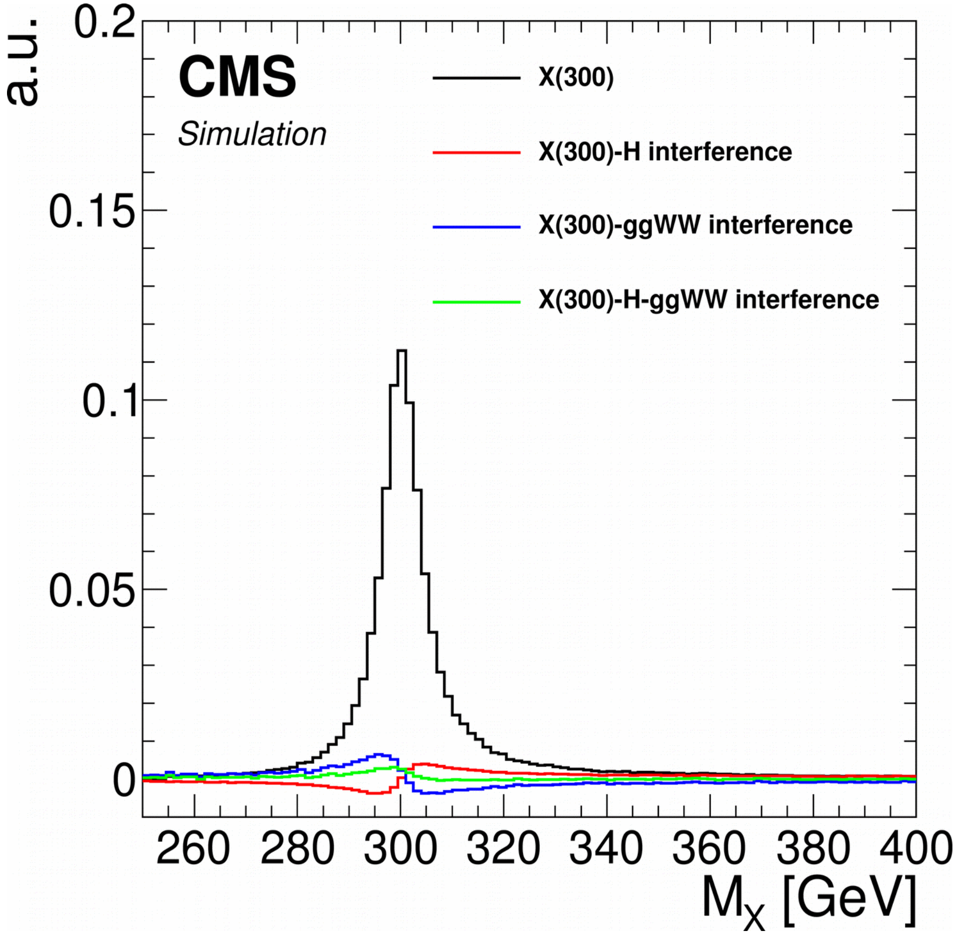
$m_{T,i}$ allows a better distinction among different signal mass hypothesis than m_T^H



1-jet

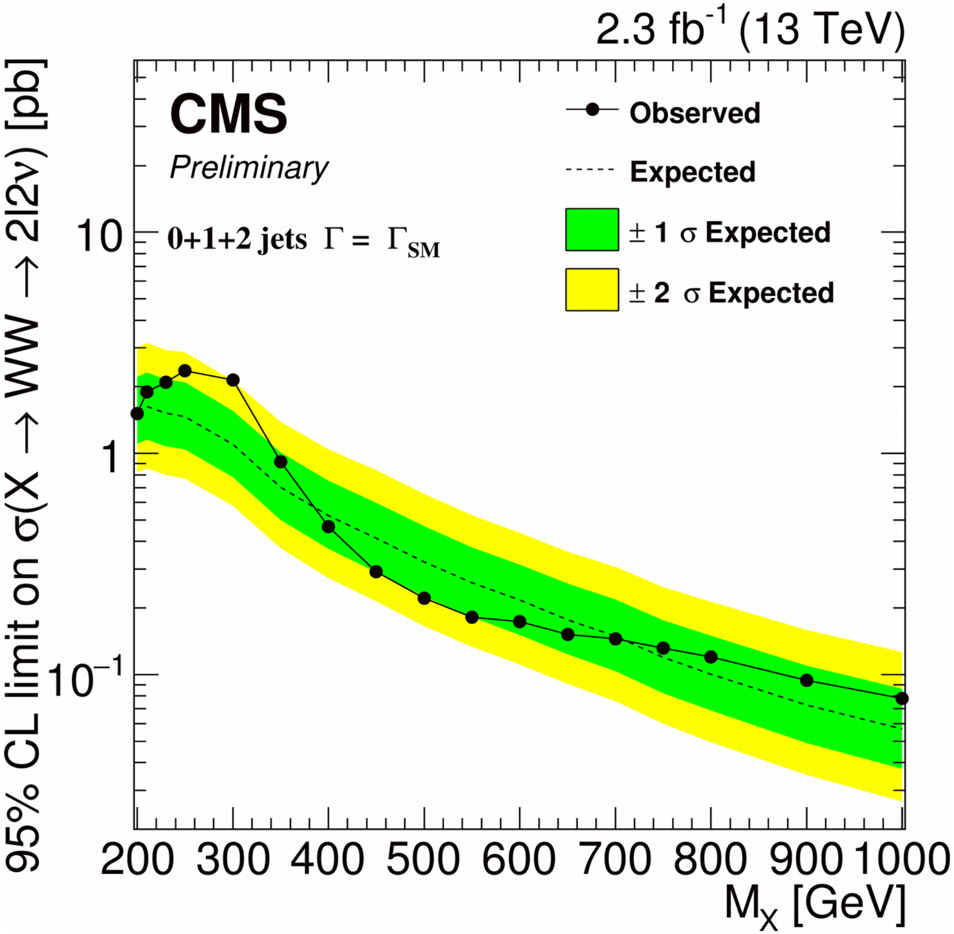
Singal model and Interference

The signal model includes the terms of interference between the gg→X→WW and the gg→WW processes, as well as the term that arises from the interference with the off-shell tail of the gg→H→WW contribution. The two interference terms partially **cancel out** and the total contribution is ~1-10% with respect to the signal.



Expected and observed limits

Expected and observed exclusion limit for the combintion of the three jet categories.
No significant excess with respect to the SM background has been observed.



Conclusion

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Standard Model Higgs analysis :

- Significance=0.7σ (expected 2.0σ).
- Signal strength: σ/σ(SM)= 0.3 ± 0.5
- 2016 results coming soon… stay tuned.

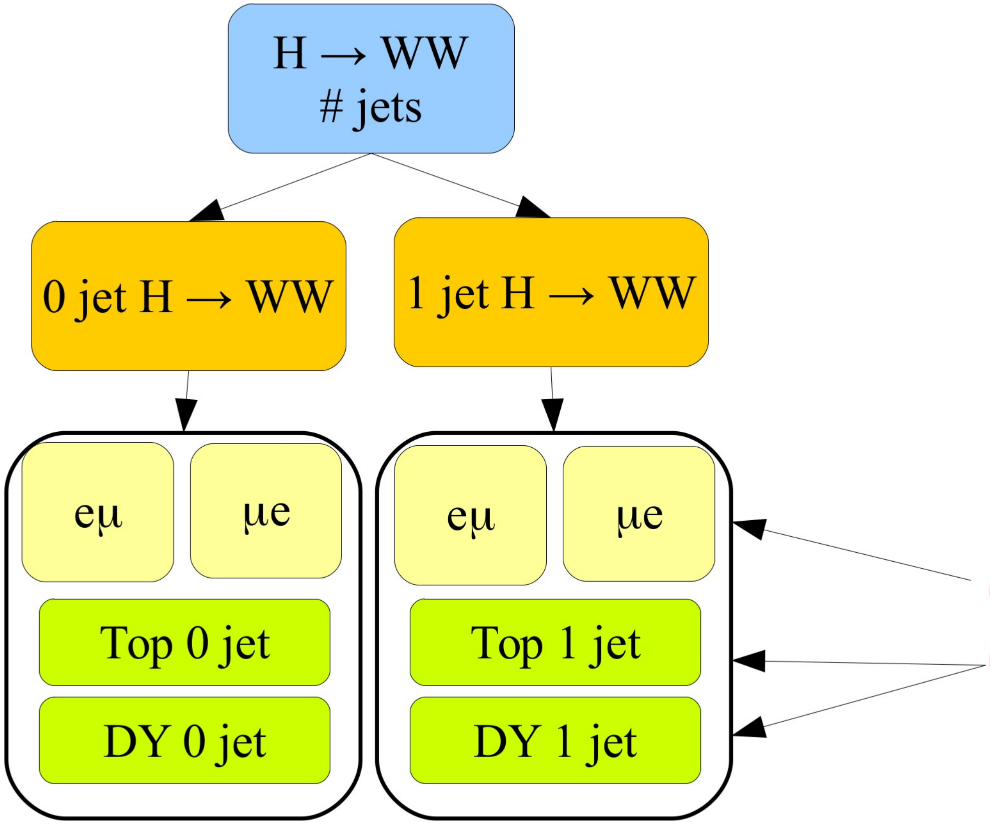
} Low Stat.

High mass analysis:

- No significant excess has been observed.
- We are looking in 2016 data.

Thanks!

backup



- Signal phase space
- Phase space to normalize the backgrounds

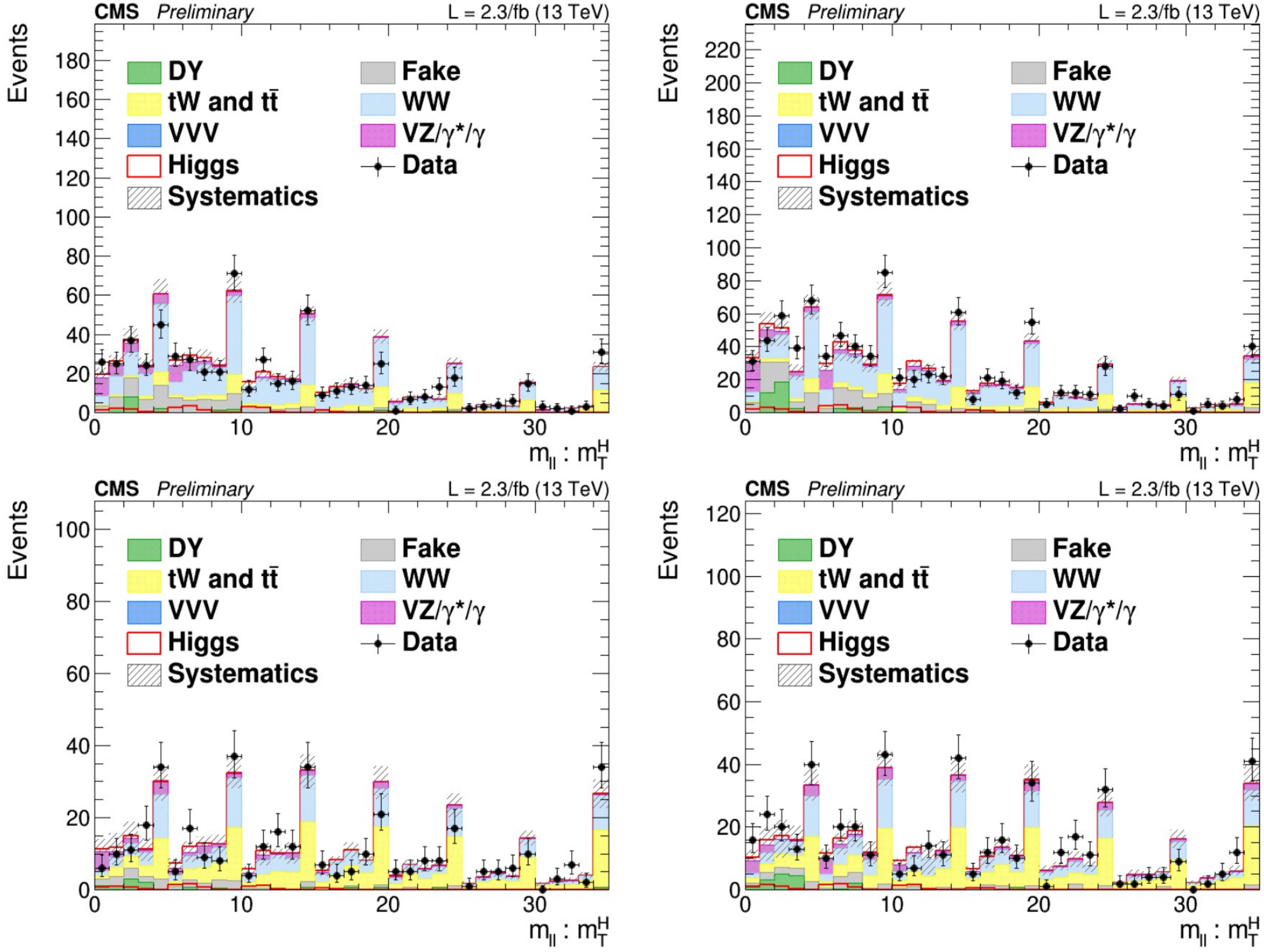


Figure 5: Bi-dimensional distributions of the $m_{\ell\ell}$ and $m_{\mathrm{T}}^{\mathrm{H}}$ templates in the 0-jet (top) and 1-jet (bottom) and μe (left) and eμ (right) categories after the WW level selection. The bi-dimensional templates ranges are $10 < m_{\ell\ell} < 110\,\mathrm{GeV}$ and $0 < m_{\mathrm{T}}^{\mathrm{H}} < 200\,\mathrm{GeV}$ with 5 bins in $m_{\ell\ell}$ and 10 bins in $m_{\mathrm{T}}^{\mathrm{H}}$. The distributions are unrolled to one dimensional histograms such that that identical values of $m_{\mathrm{T}}^{\mathrm{H}}$ are in adjacent bins. The background and signal contributions are normalized according to their pre-fit values except that scale factors estimated from data are applied to the jet induced, the Drell-Yan, and top backgrounds.

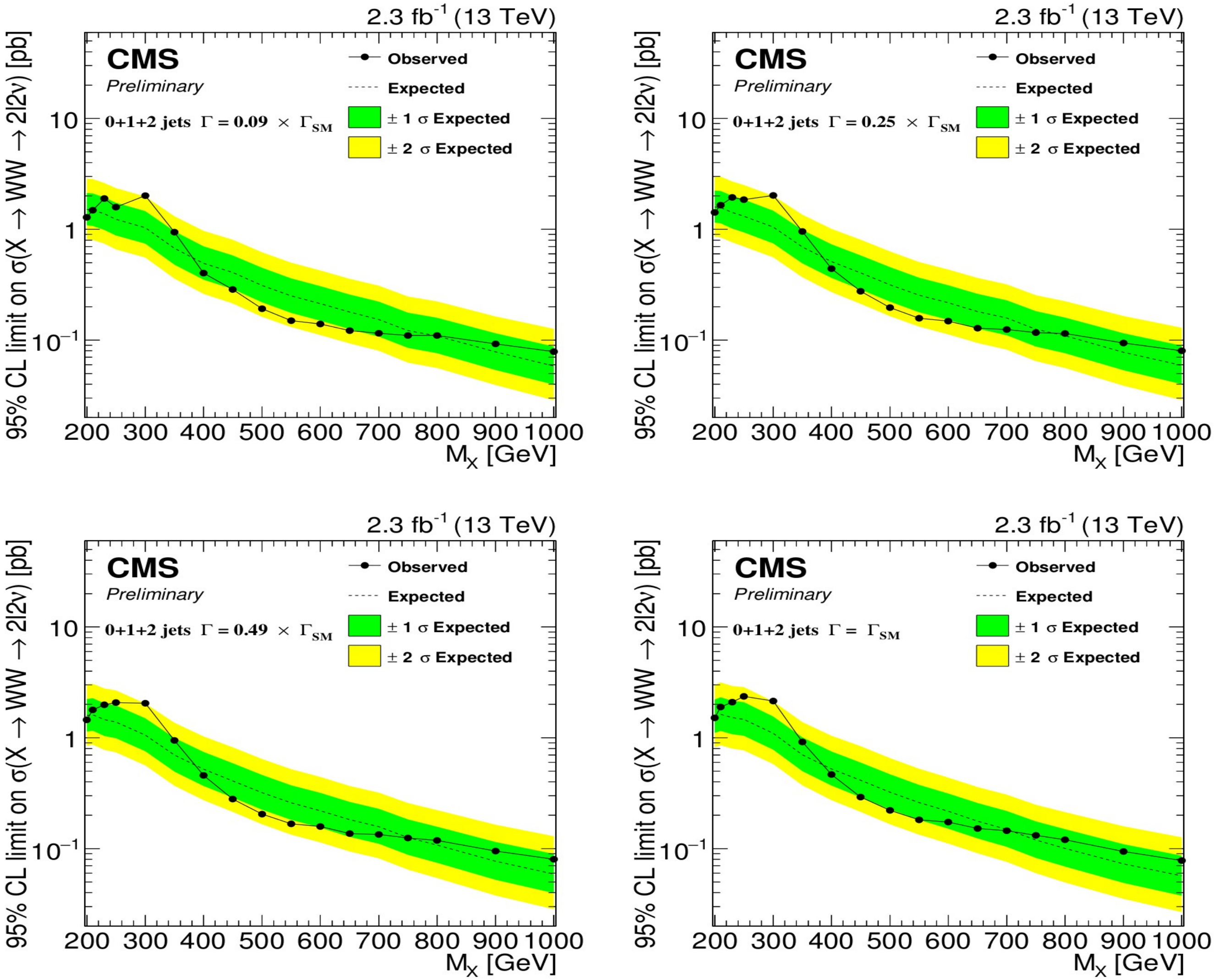
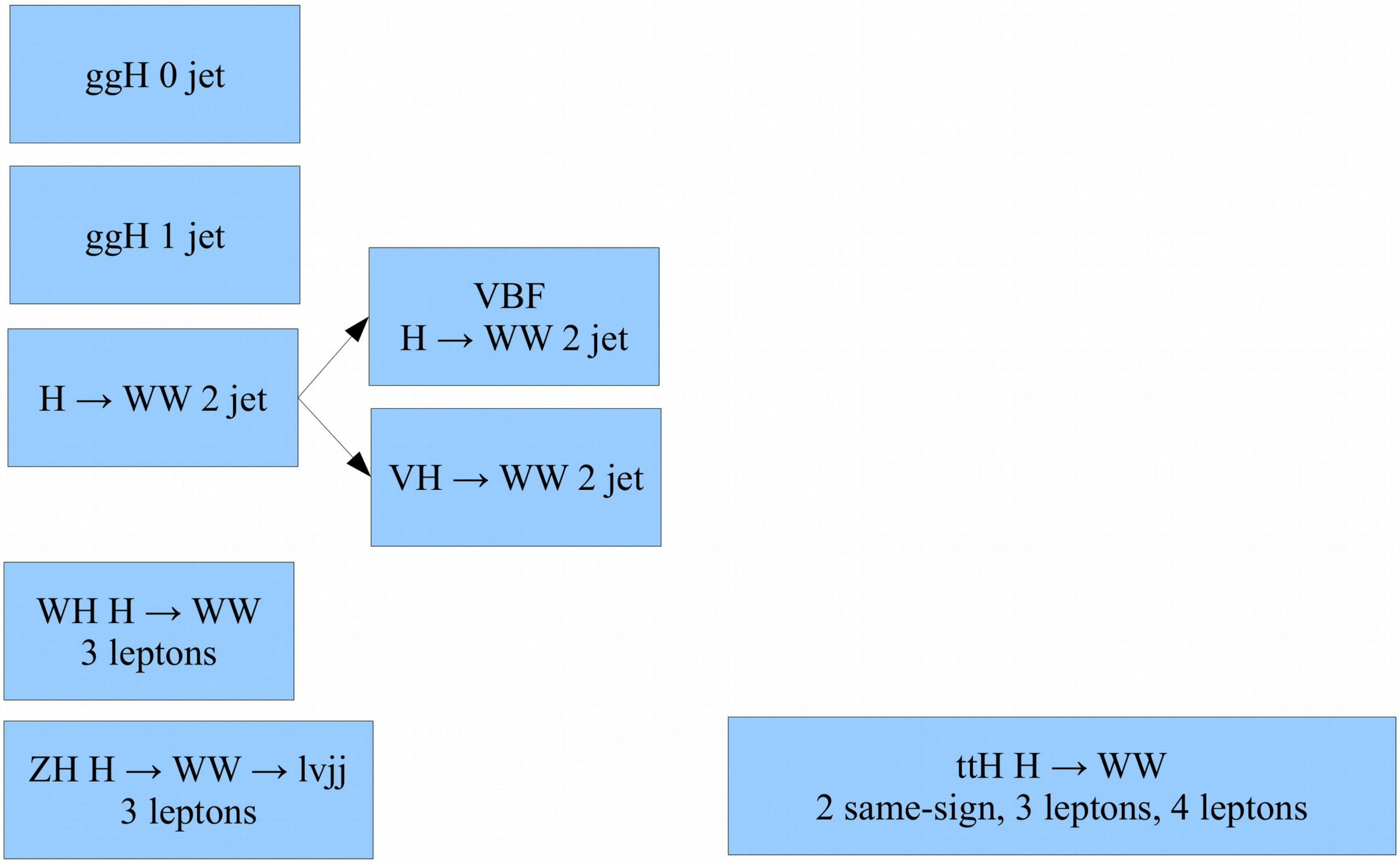


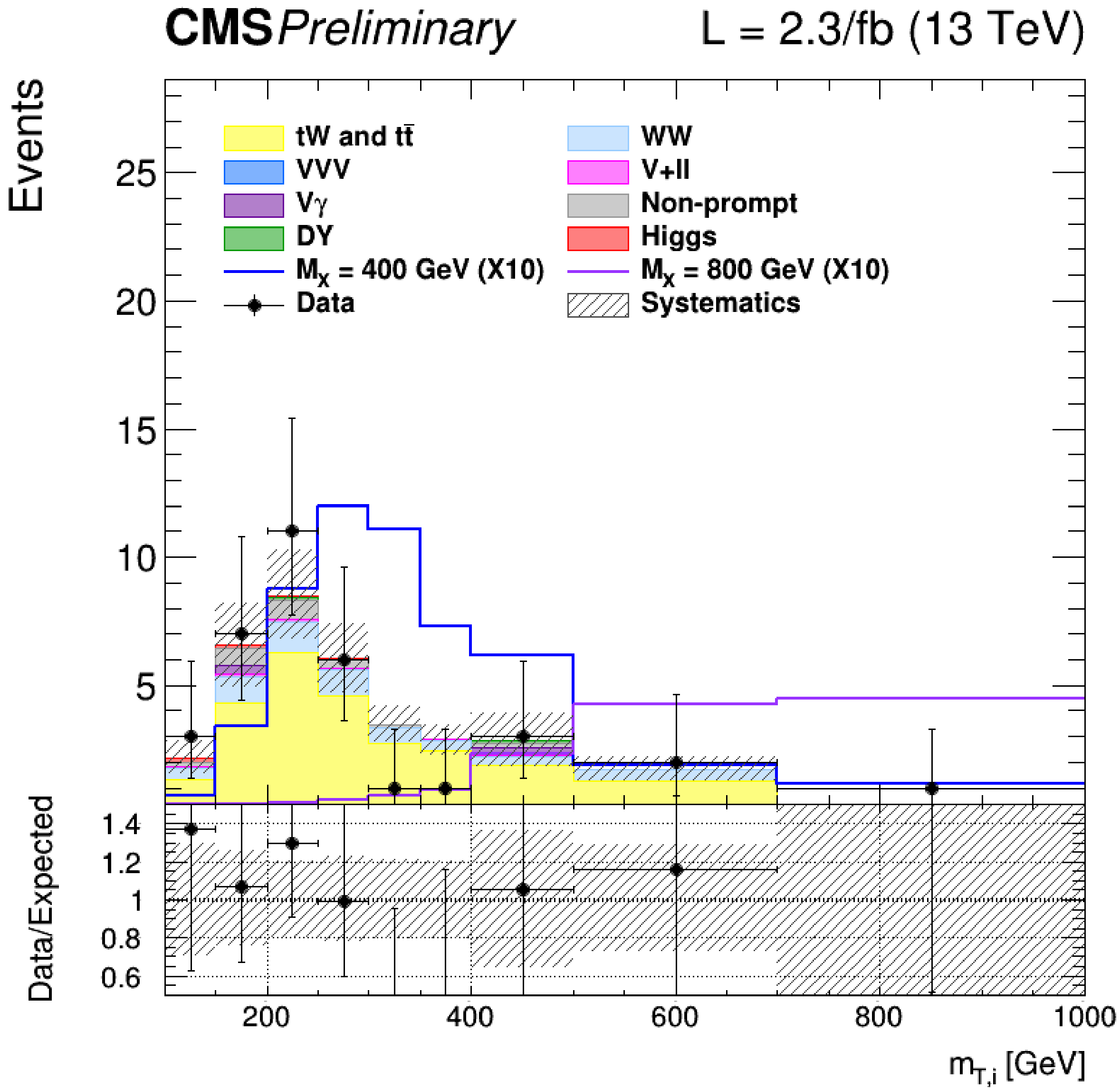
Figure 5: Expected and observed exclusion limits at 95% CL on the sum of ggH and VBF cross sections times branching fraction for the combination of the three jet categories as a function of the resonance mass. The black dotted line corresponds to the central value while the yellow and green bands represent the $\pm1\sigma$ and $\pm2\sigma$ uncertainties respectively. Limits are shown for four hypothesis of the signal width.

7-8 TeV results



7-8 TeV results

	Significance Obs Exp		σ/σ_{SM}
combination	4.3σ	5.8σ	$0.72^{+0.20}_{-0.18}$
$e\mu$ alone 0/1 jet	4.0σ	5.2σ	0.76 ± 0.21



CMS Preliminary
L = 2.3/fb (13 TeV)
Events
tW and tt̄
WW
VVV
V+ll
Vγ
Non-prompt
DY
Higgs
M$_X$ = 400 GeV (X10)
M$_X$ = 800 GeV (X10)
Data
Systematics
Data/Expected
$m_{T,i}$ [GeV]

VBF

Table 1: Observed p-value and corresponding significance (set to 0 in case of underfluctuations of the observed number of events) for the combination of the three jet categories for different resonance masses. Different values of the signal width are shown.

Mass [GeV]	$\Gamma = 0.09 \times \Gamma_{SM}$ p-value (signif.)	$\Gamma = 0.25 \times \Gamma_{SM}$ p-value (signif.)	$\Gamma = 0.49 \times \Gamma_{SM}$ p-value (signif.)	$\Gamma = \Gamma_{SM}$ p-value (signif.)
200	0.50 (0)	0.50 (0)	0.50 (0)	0.56 (0)
210	0.58 (0)	0.45 (0.1)	0.35 (0.4)	0.24 (0.7)
230	0.21 (0.8)	0.22 (0.8)	0.23 (0.7)	0.26 (0.6)
250	0.29 (0.5)	0.20 (0.8)	0.15 (1.0)	0.12 (1.2)
300	0.014 (2.2)	0.015 (2.2)	0.016 (2.1)	0.018 (2.1)
350	0.16 (1.0)	0.17 (1.0)	0.18 (0.9)	0.23 (0.7)
400	0.50 (0)	0.49 (0)	0.49 (0)	0.57 (0)
450	0.51 (0)	0.50 (0)	0.50 (0)	0.52 (0)
500	0.50 (0)	0.51 (0)	0.50 (0)	0.52 (0)
550	0.50 (0)	0.51 (0)	0.51 (0)	0.51 (0)
600	0.50 (0)	0.50 (0)	0.51 (0)	0.51 (0)
650	0.50 (0)	0.50 (0)	0.54 (0)	0.50 (0)
700	0.50 (0)	0.50 (0)	0.50 (0)	0.50 (0)
750	0.50 (0)	0.54 (0)	0.50 (0)	0.40 (0.3)
800	0.50 (0)	0.55 (0)	0.39 (0.3)	0.29 (0.6)
900	0.29 (0.6)	0.27 (0.6)	0.24 (0.7)	0.22 (0.8)
1000	0.18 (0.9)	0.18 (0.9)	0.18 (0.9)	0.18 (0.9)