

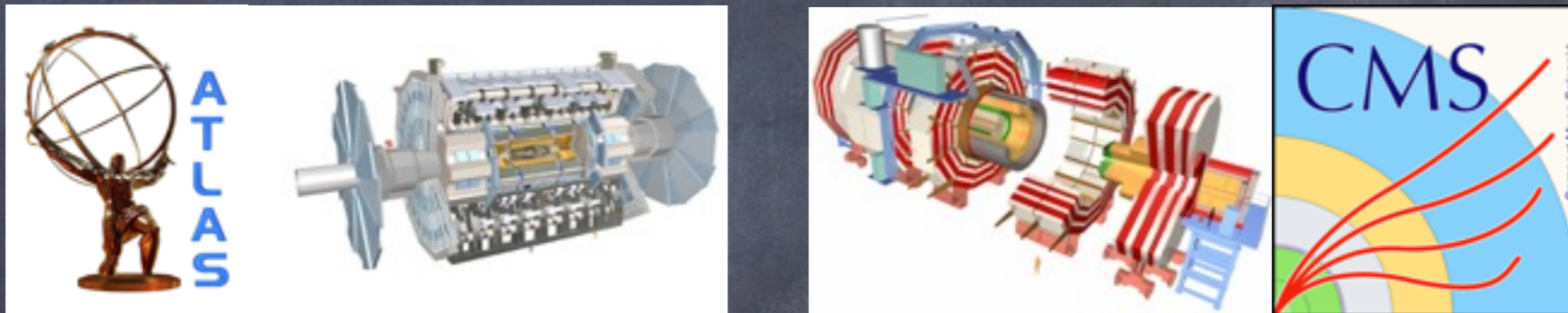
Search for the Higgs the associated production excluding $t\bar{t}H$ (Run I & 2 perspective)

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(For ATLAS & CMS collaboration)



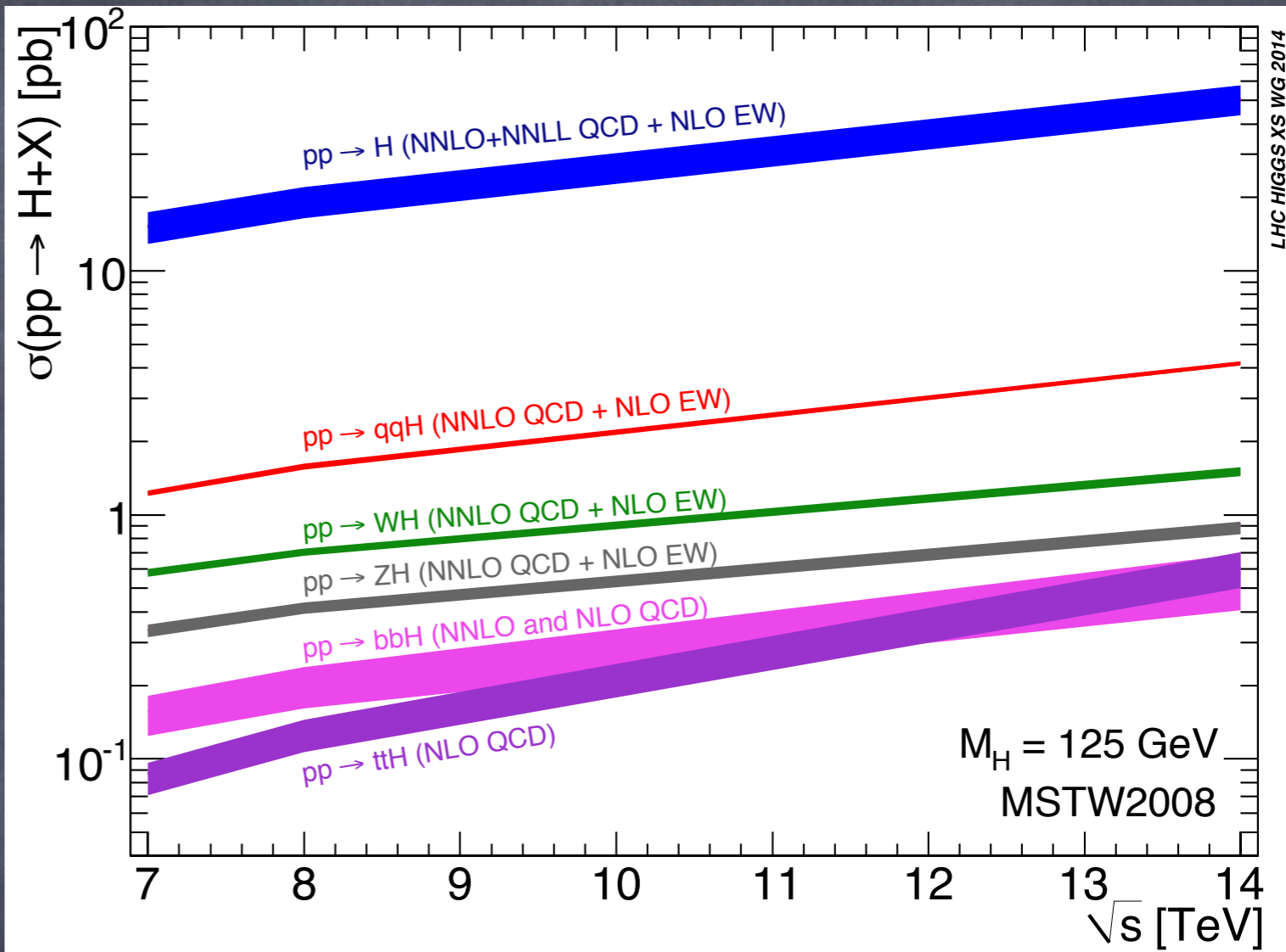
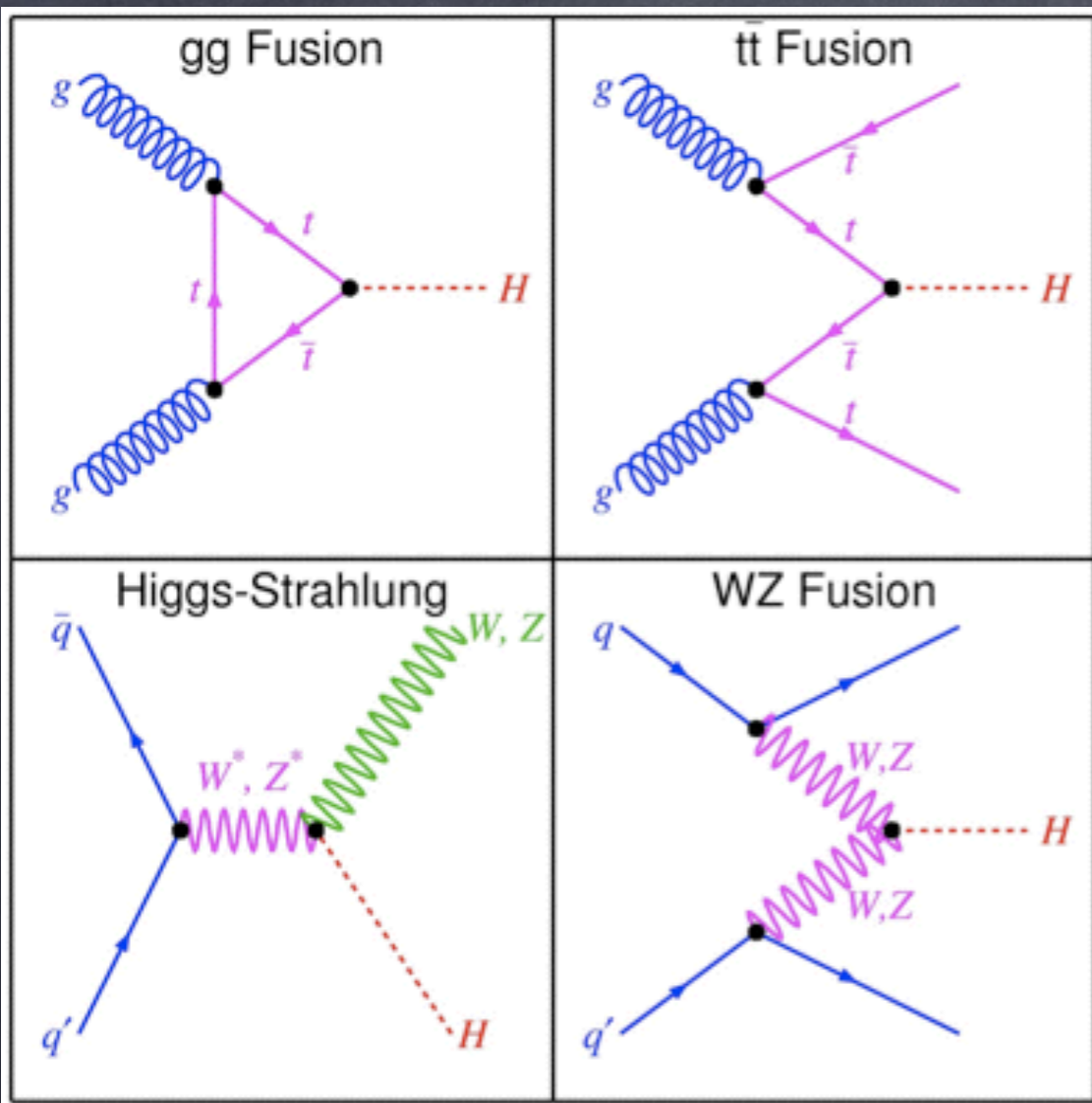
25th International Workshop on Weak Interactions & Neutrinos
Heidelberg, Germany
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Outline

- Leading production mechanism at the LHC for the Standard Model (SM) Higgs boson
- Accessible decay modes of the SM Higgs boson at the LHC
- ATLAS & CMS search results from different bosonic decay modes of the SM Higgs boson
- Differential and total cross-section measurement
- Run II prospects
- Summary & Conclusions

Production of the SM Higgs



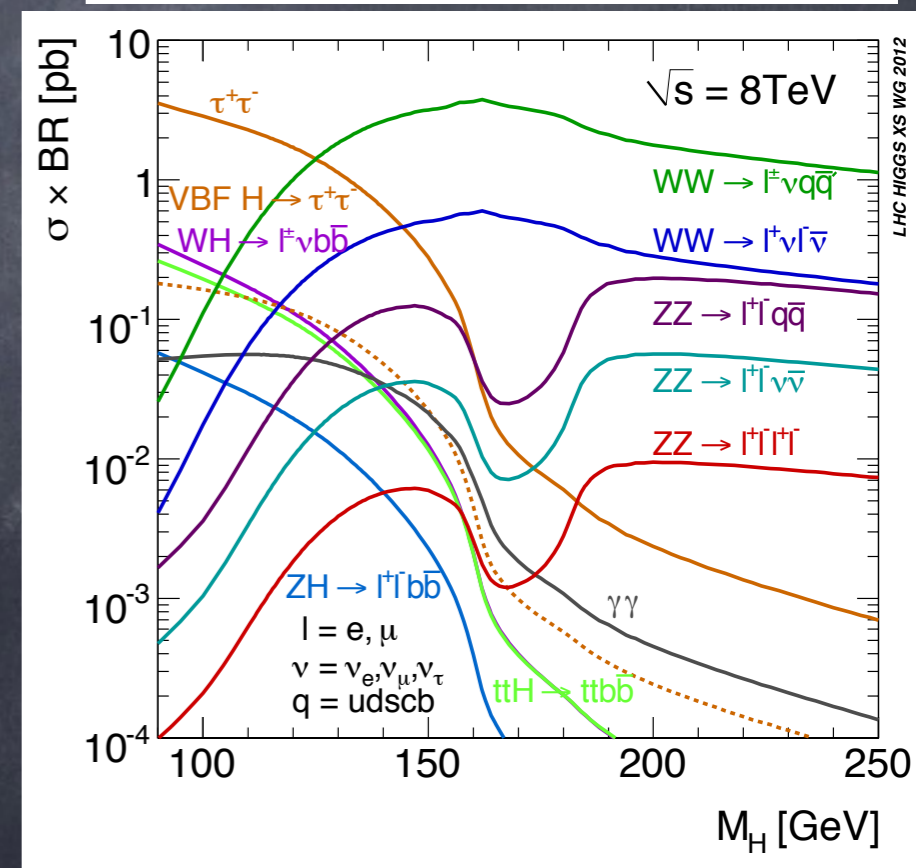
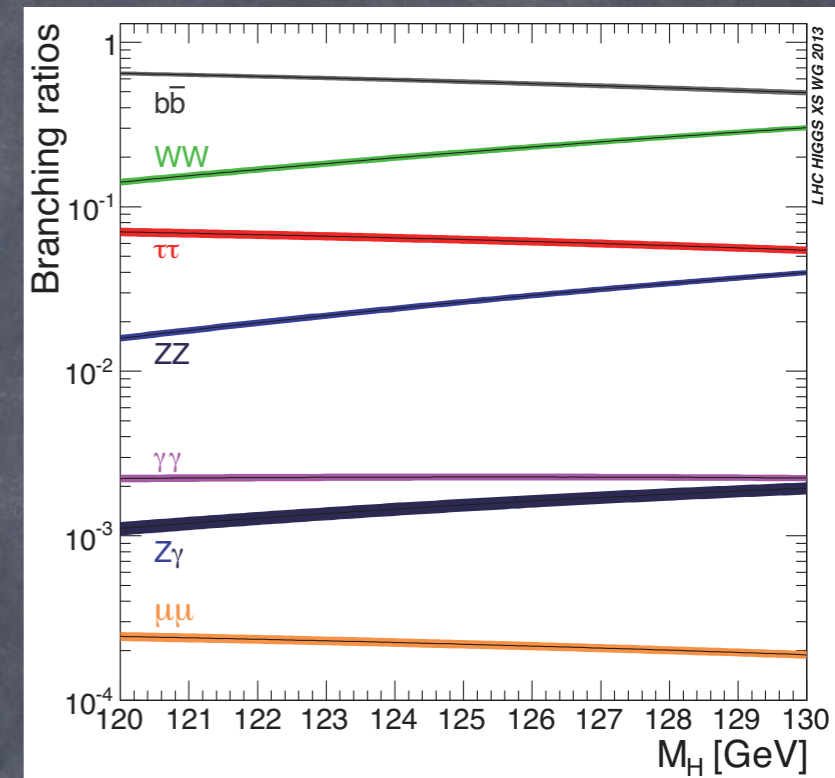
- Gluon-gluon fusion (ggF) has the highest production cross-section at the LHC
- **Vector boson fusion (VBF) and vector boson associated production (VH) modes have the next dominant contribution.**
- ttH would be covered in another talk (see the talk by Daniele Zanzi)



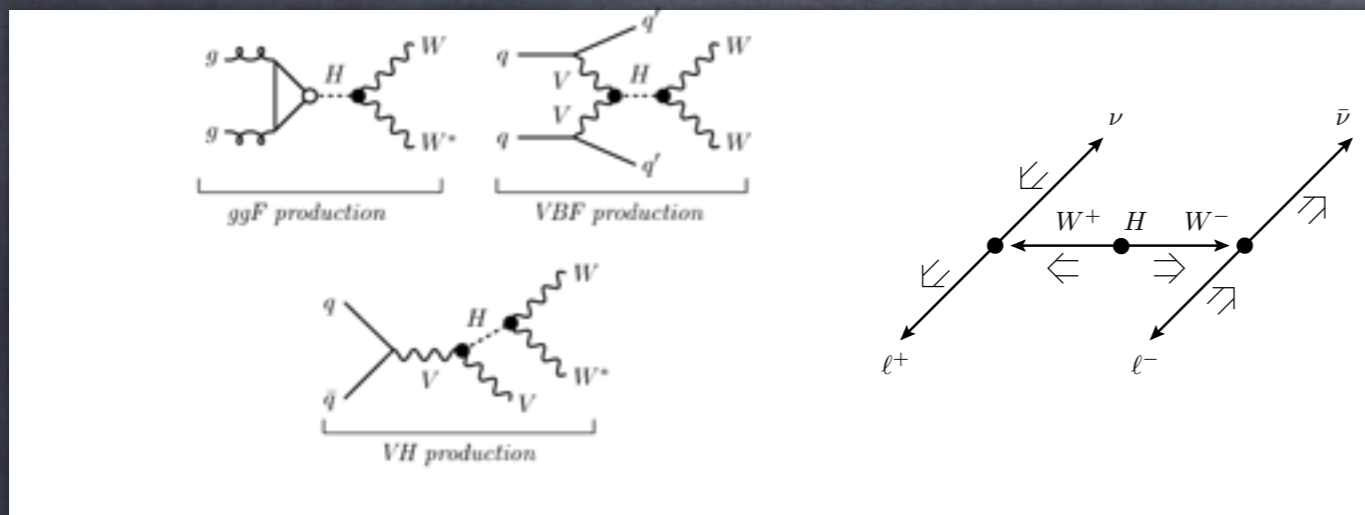
Decay of the SM Higgs



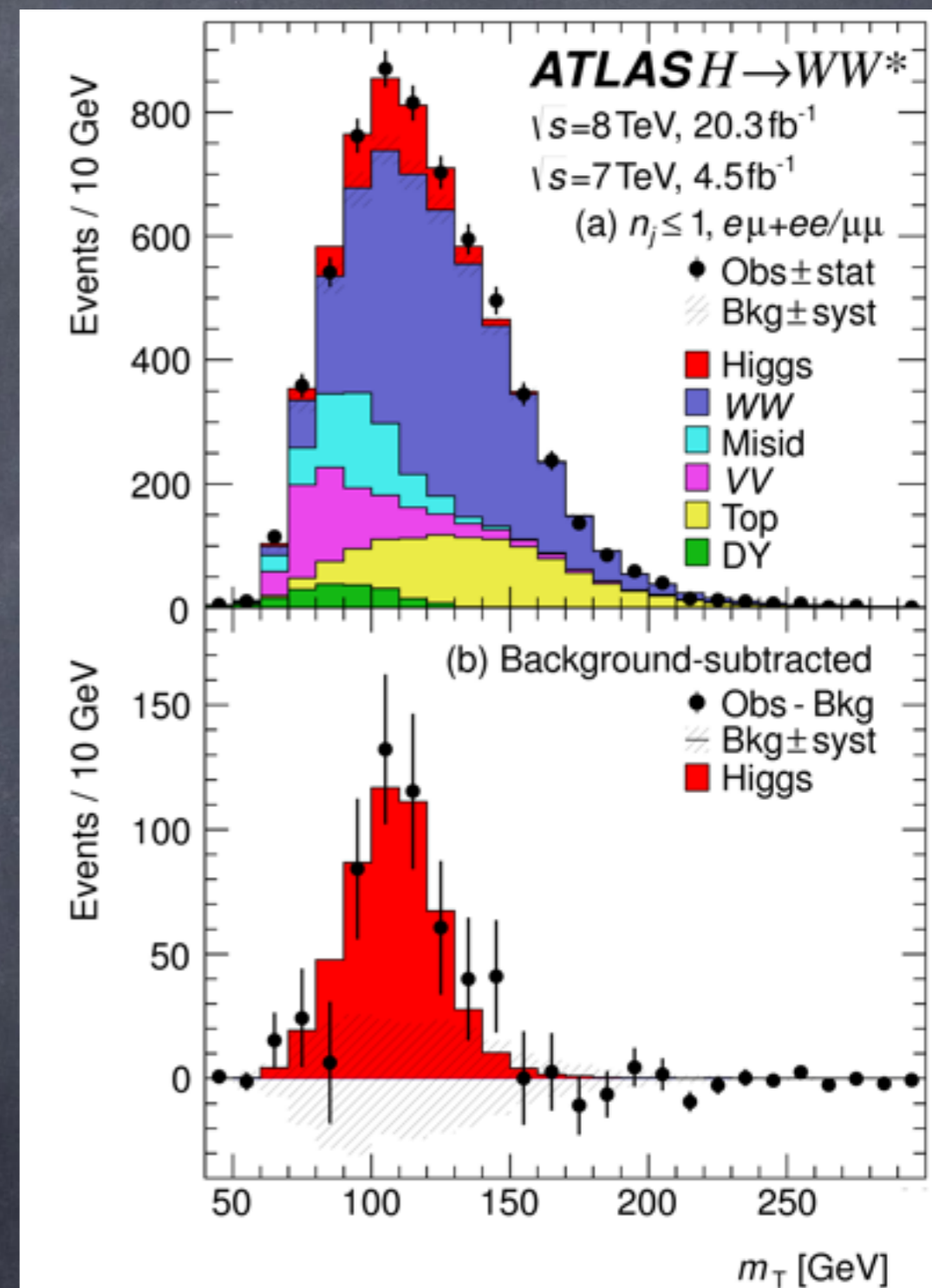
- SM Higgs boson decay branching ratio (accessible at $m_H=125$ GeV):
 - fermionic decay modes — $b\bar{b}$, $\tau\tau$, $\mu\mu$ (NOT included in this talk)
 - SM Higgs decays into vector bosons (with subsequent decays)
 - $H \rightarrow WW$ (0.215)
 - $H \rightarrow ZZ$ (0.026)
 - $H \rightarrow \gamma\gamma$ (0.0023)
 - $H \rightarrow Z\gamma$ (0.0015)



Search for $H \rightarrow WW \rightarrow l\nu l\nu$



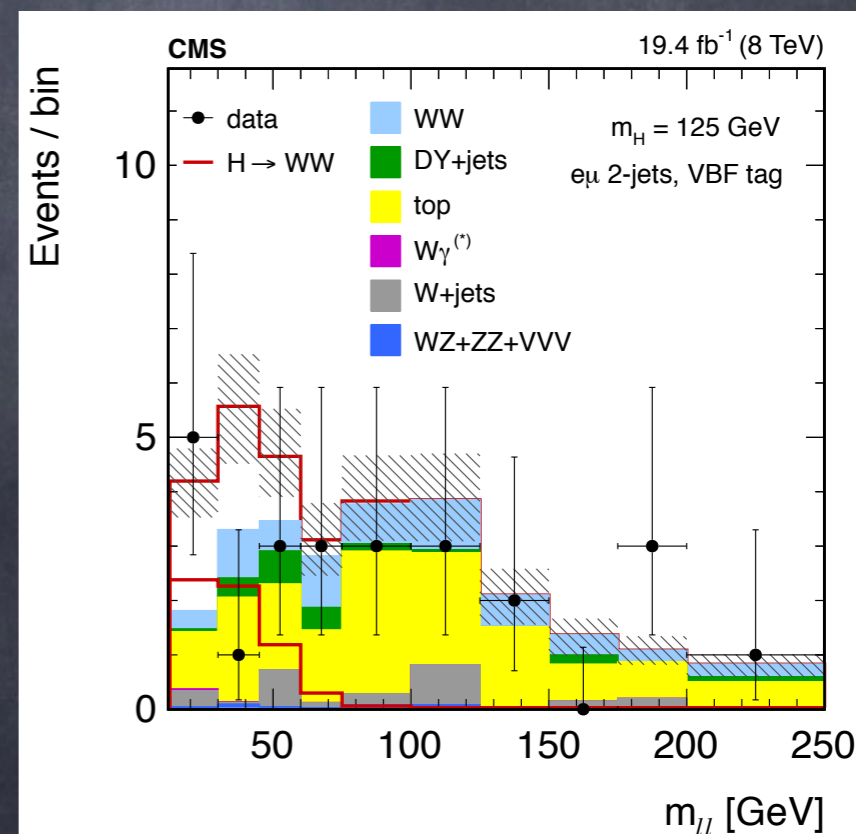
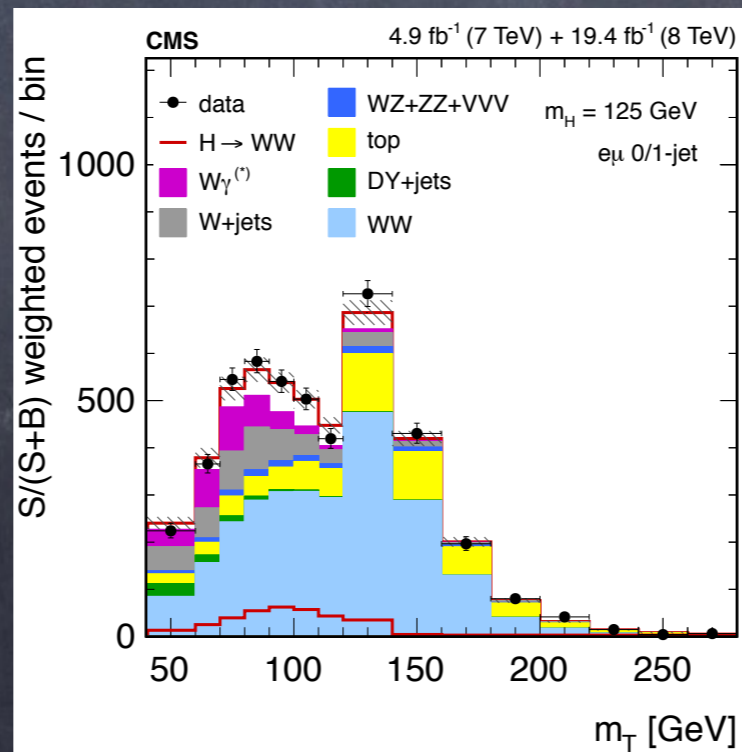
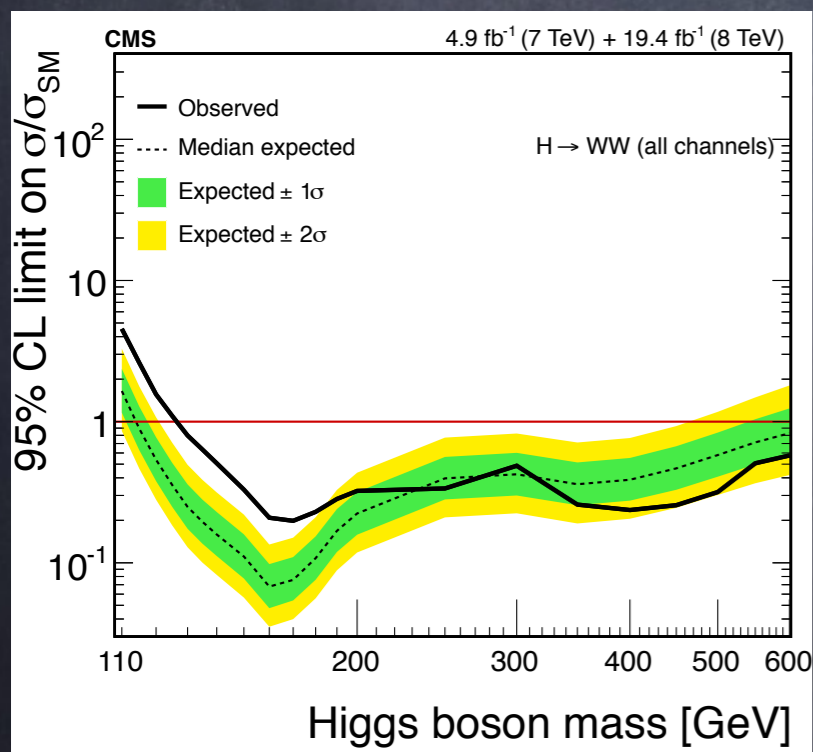
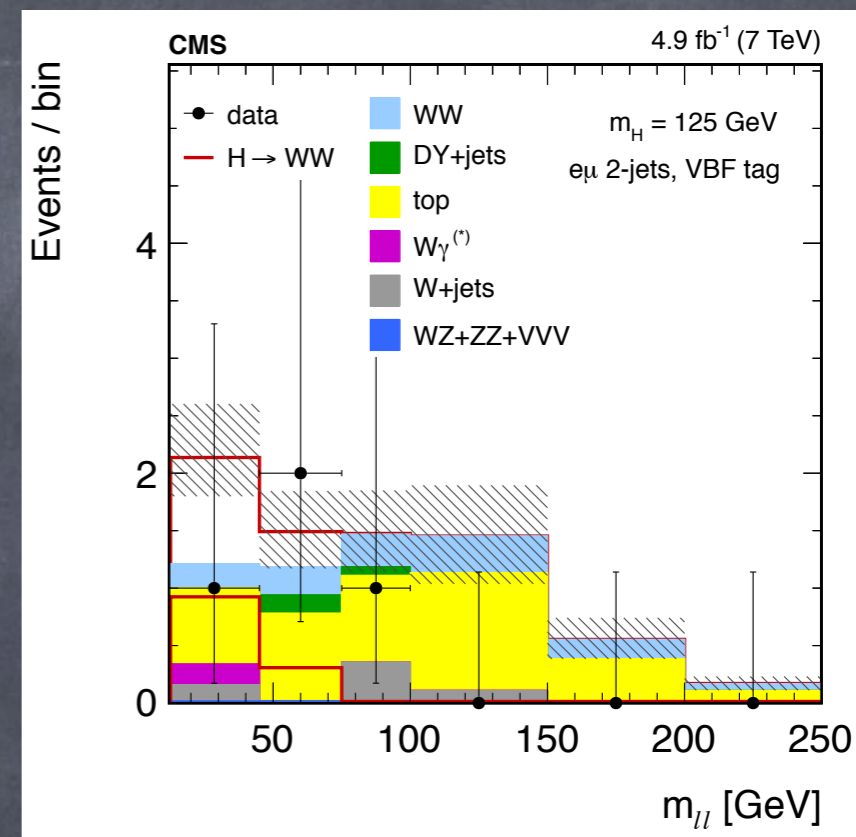
- Large branching fraction and accessible also through VBF & VH production
 - 2 leptons:
 - $n_{\text{jets}}=0, 1 \text{ \& } 2$ (VBF enriched)
 - $(W/Z)H \rightarrow (W/Z)WW \rightarrow (qq')l\nu l\nu$
 - 3 leptons: $WH \rightarrow (W)WW \rightarrow (l\nu)l\nu l\nu$
 - 4 leptons: $ZH \rightarrow (Z)WW \rightarrow (ll)l\nu l\nu$
- Large missing E_T contribution from the neutrinos with two or more high- p_T , isolated leptons
- Discriminating variables m_T , m_{ll} , ΔR_{ll} and $\Delta \Phi_{ll}$
- Background processes: SM diboson production, $t\bar{t}$, and misidentified leptons



[CERN-PH-EP-2014-270/arXiv:1412.2641](https://arxiv.org/abs/1412.2641)

Search for $H \rightarrow WW \rightarrow \ell\nu\ell\nu$ (II)

- CMS analyses are categorized into 2-leptons and 3-leptons final states
 - 2-leptons: 0/1-jet ggF tag, 2-jets VBF tag, 2-jets VH tag
 - 3-leptons: $WH \rightarrow \ell\nu\ell\nu$ and $ZH \rightarrow \ell\ell\nu + 2$ jets
- Signal events are extracted either through template fit or counting



[CMS-HIG-13-023/arXiv:1312.1129](https://arxiv.org/abs/1312.1129)



Search for $H \rightarrow WW \rightarrow l\nu l\nu$ (III)



ATLAS ($m_H @ 125.36$ GeV):

$$\mu_{ggF} = 1.02 \pm 0.19 \begin{matrix} +0.22 \\ -0.18 \end{matrix} = 1.02 \begin{matrix} +0.29 \\ -0.26 \end{matrix}$$

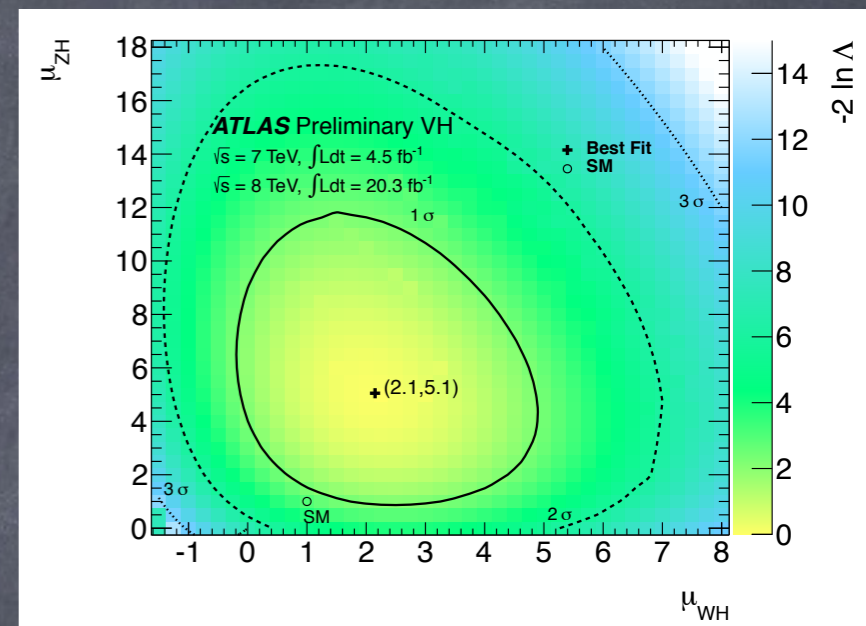
$$\mu_{VBF} = 1.27 \begin{matrix} +0.44 \\ -0.40 \end{matrix} \begin{matrix} +0.30 \\ -0.21 \end{matrix} = 1.27 \begin{matrix} +0.53 \\ -0.45 \end{matrix}$$

(stat.) (syst.)

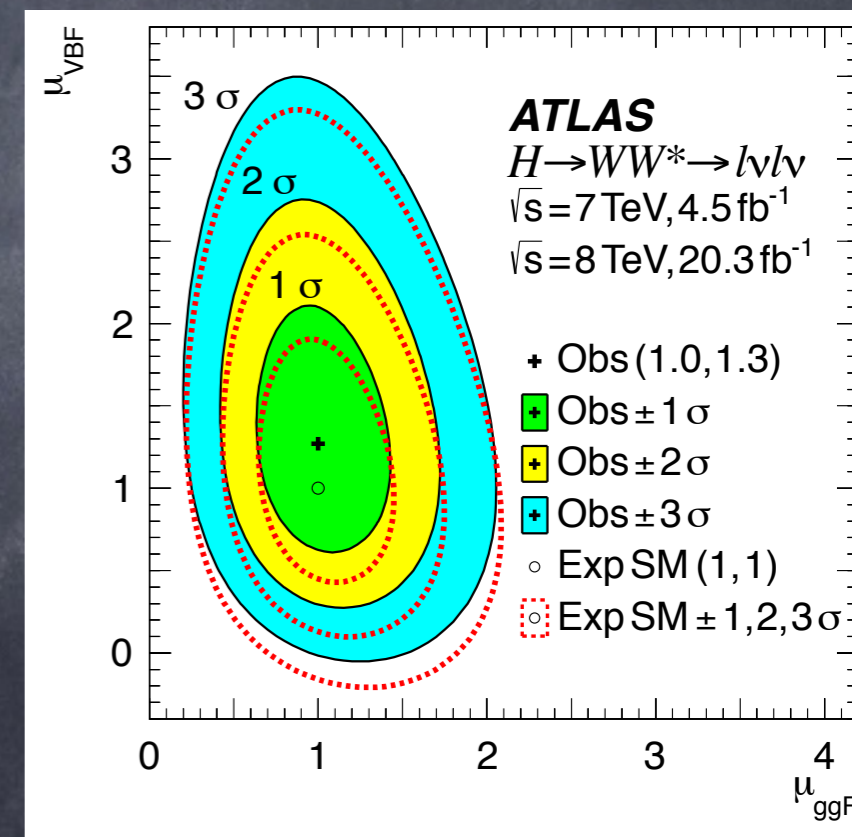
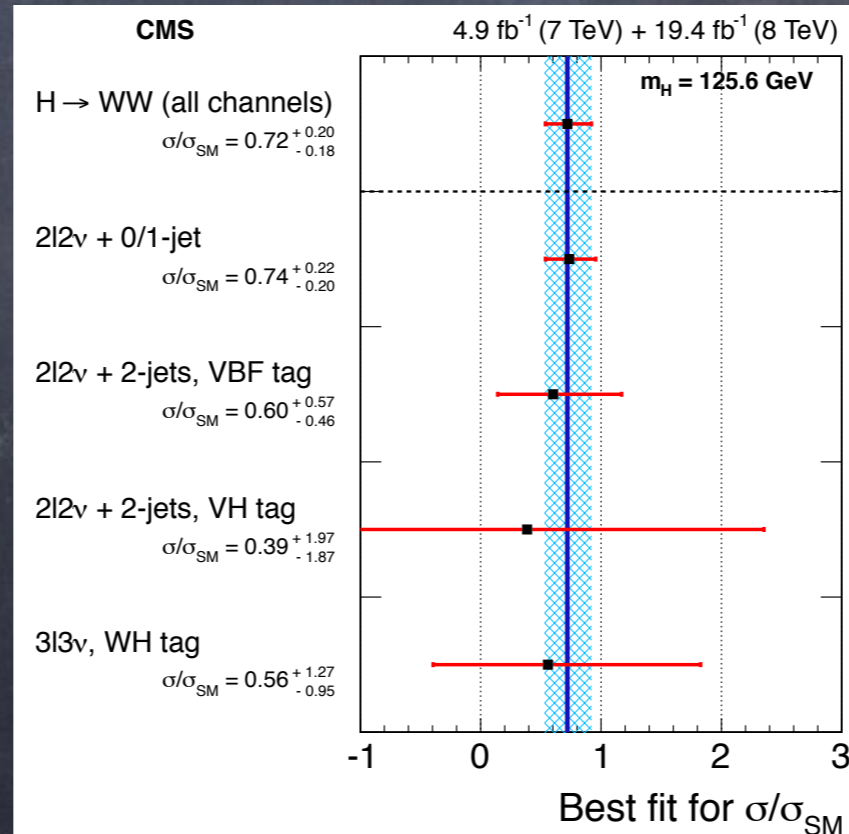
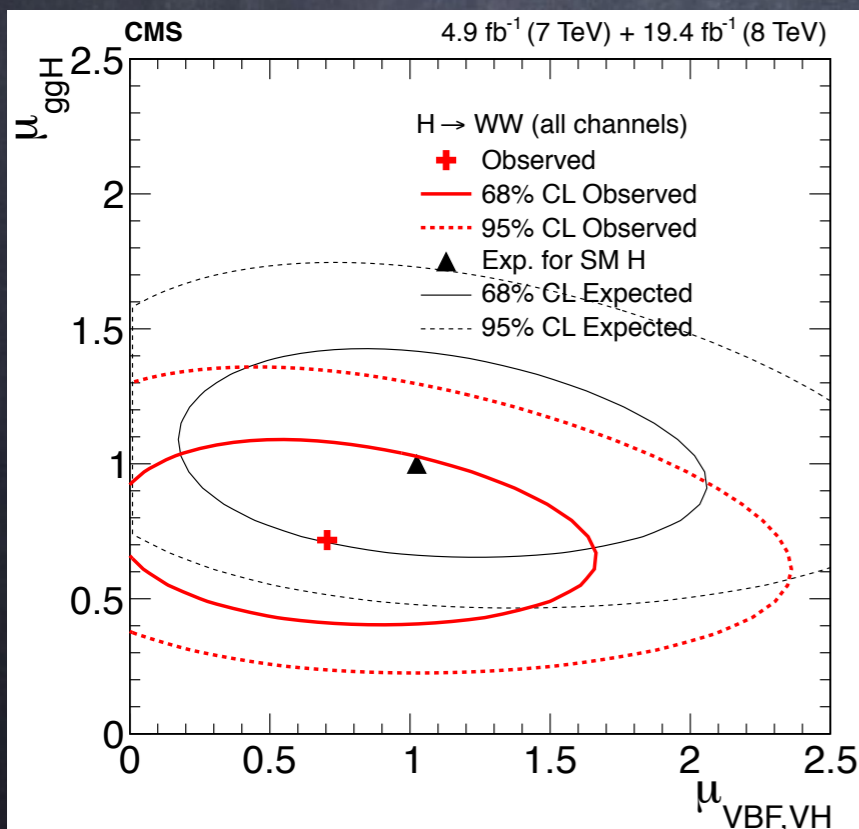
CMS ($m_H @ 125.6$ GeV):

$$\mu_{incl.} = 0.72^{+0.12}_{-0.12} (\text{stat})^{+0.12}_{-0.10} (\text{th syst})^{+0.10}_{-0.10} (\text{exp syst})$$

CMS-HIG-13-023



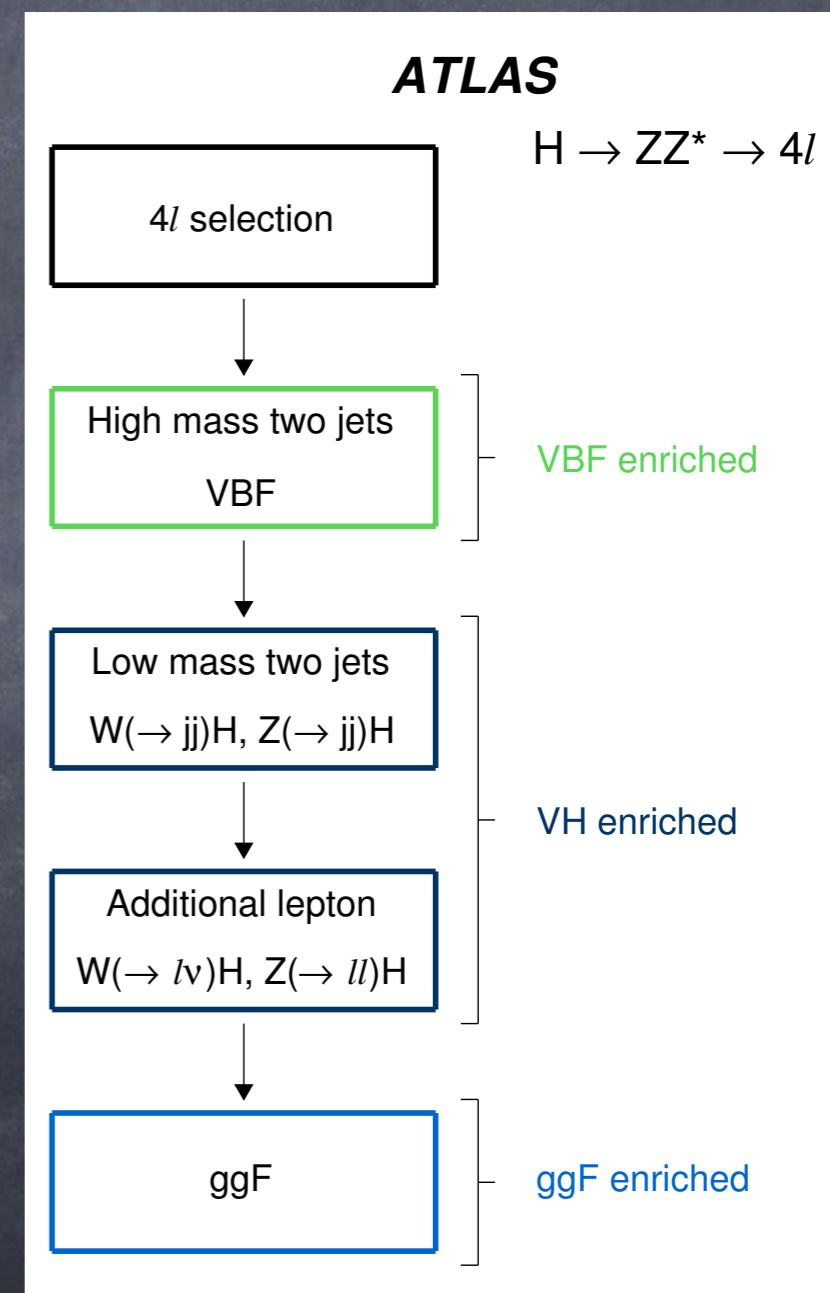
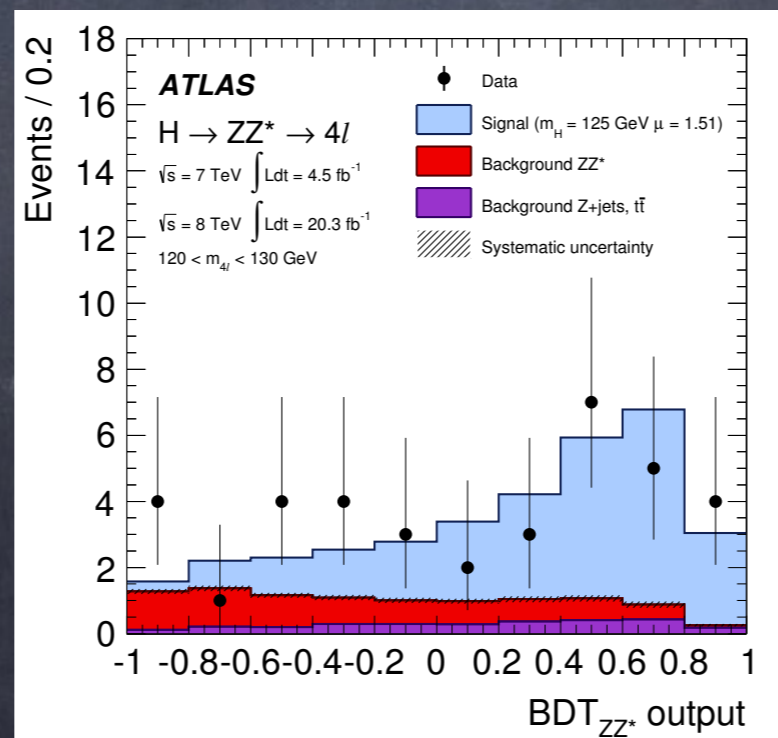
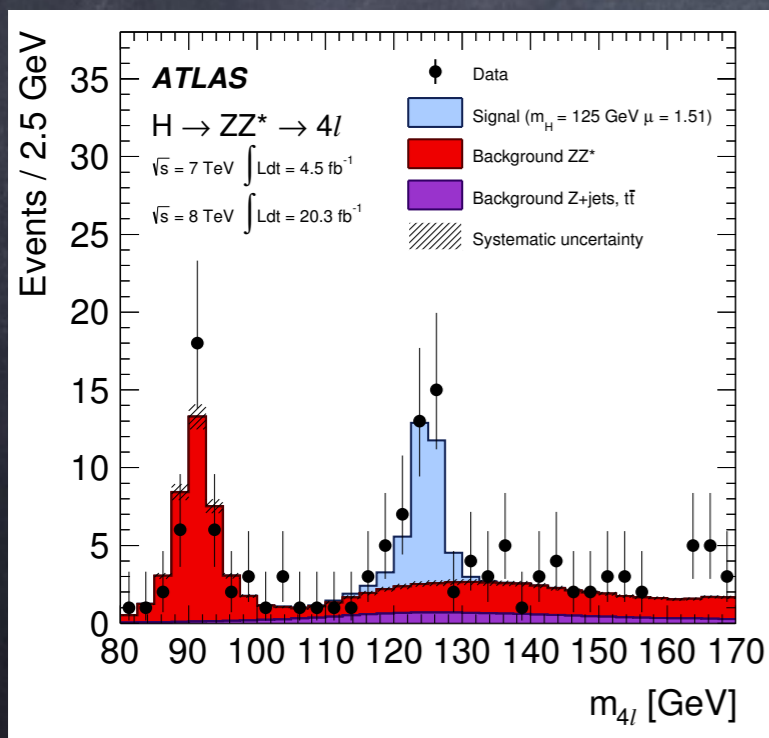
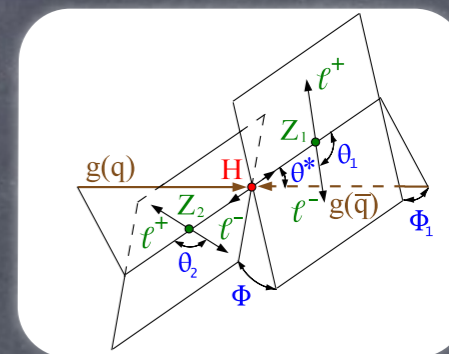
ATLAS-CONF-2015-005



arXiv:1412.2641

Search for $H \rightarrow ZZ \rightarrow 4l$

- Fully reconstructed event topology with four isolated leptons in the final state; clean channel with high S/\sqrt{B} , but small branching fraction
- Event categorization to separate ggF, VH and VBF
- SM ZZ is the irreducible background; multivariate discriminant for signal vs SM ZZ separation
 - BDT with input variables: p_T^{4l} , η^{4l} , $D_{ZZ} = \ln(|M_{sig}|^2 / |M_{bkg}|^2)$, with M being the Matrix Element

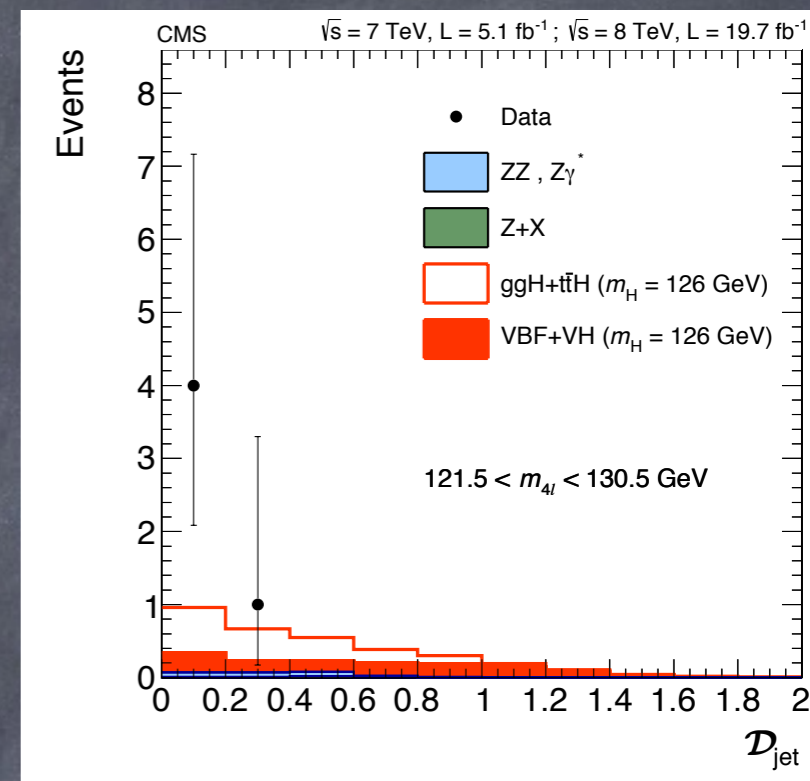


arXiv:1408.5191/PRD 91, 012006 (2015)

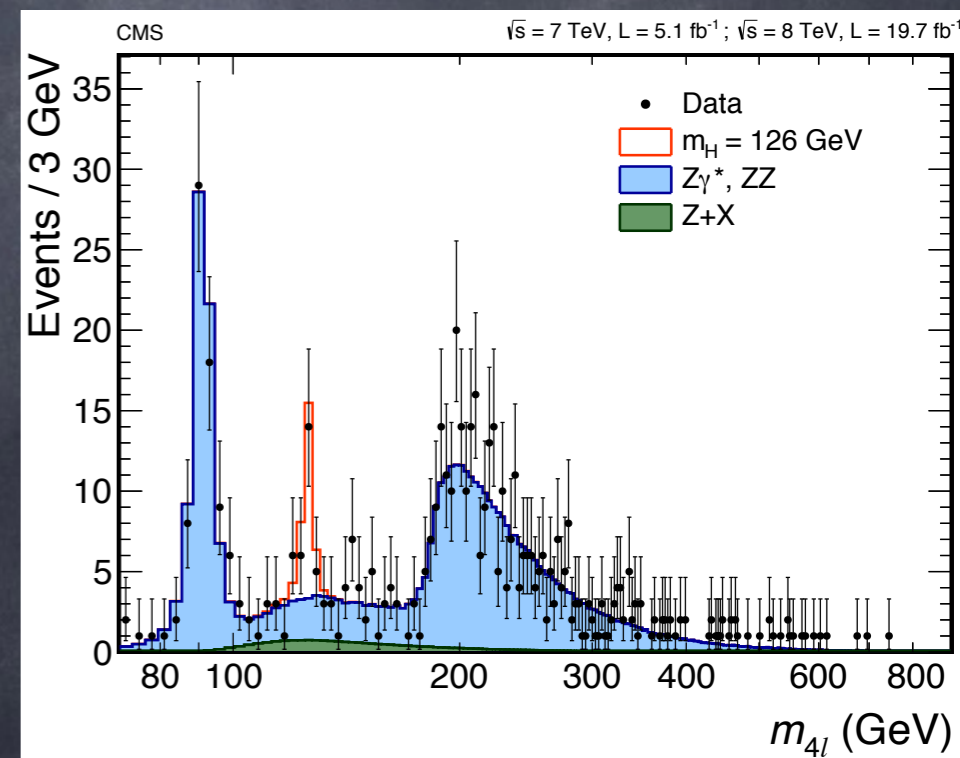
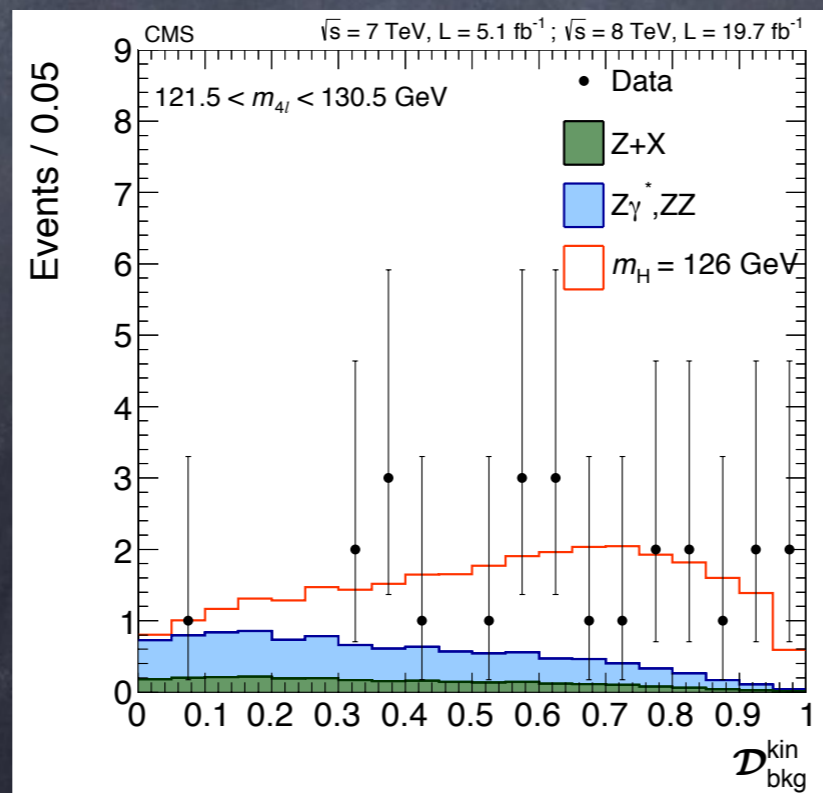
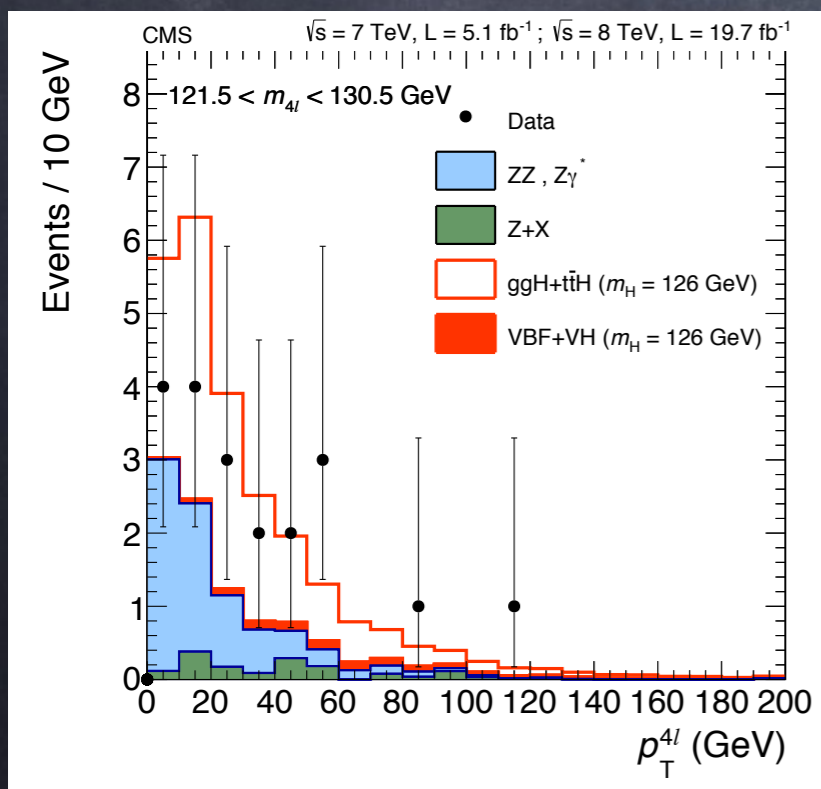
Search for $H \rightarrow ZZ \rightarrow 4l$ (II)

- Event categorization based on number of jets
 - 0/1 jet: ' p_T^{4l} ' for separation between ggF and VBF/VH
 - Dijet: Linear discriminator, ' \mathcal{D}_{jet} ' to separate ggF from VBF/VH
- multivariate discriminant for signal vs SM ZZ separation

$$D_{bkg}^{kin} = \left[1 + \frac{P_{bkg}^{kin}(m_{Z_1}, m_{Z_2}, \theta^*, \Phi_1, \theta_1, \theta_2, \Phi)}{P_{0+}^{kin}(m_{Z_1}, m_{Z_2}, \theta^*, \Phi_1, \theta_1, \theta_2, \Phi)} \right]^{-1} \text{ with } P = |M|^2$$



arXiv:1312.5353



Search for $H \rightarrow ZZ \rightarrow 4l$ (III)

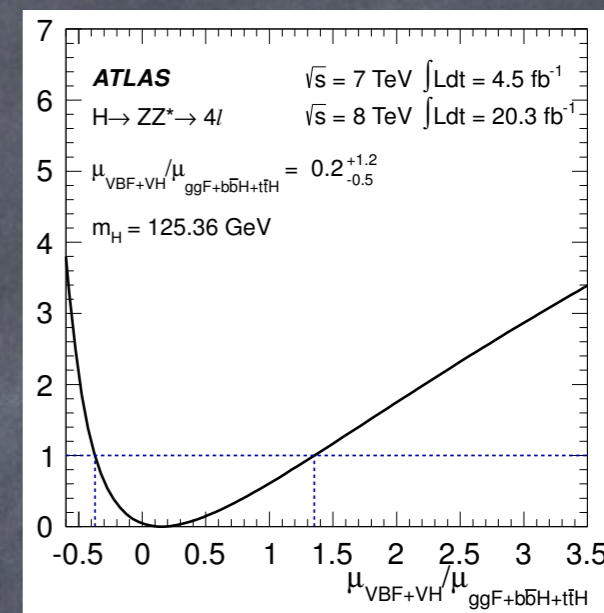
• CMS: At $m_H = 125.6$ GeV

$$\mu_{incl.} = 0.93^{+0.26}_{-0.23} (\text{stat})^{+0.13}_{-0.09} (\text{syst})$$

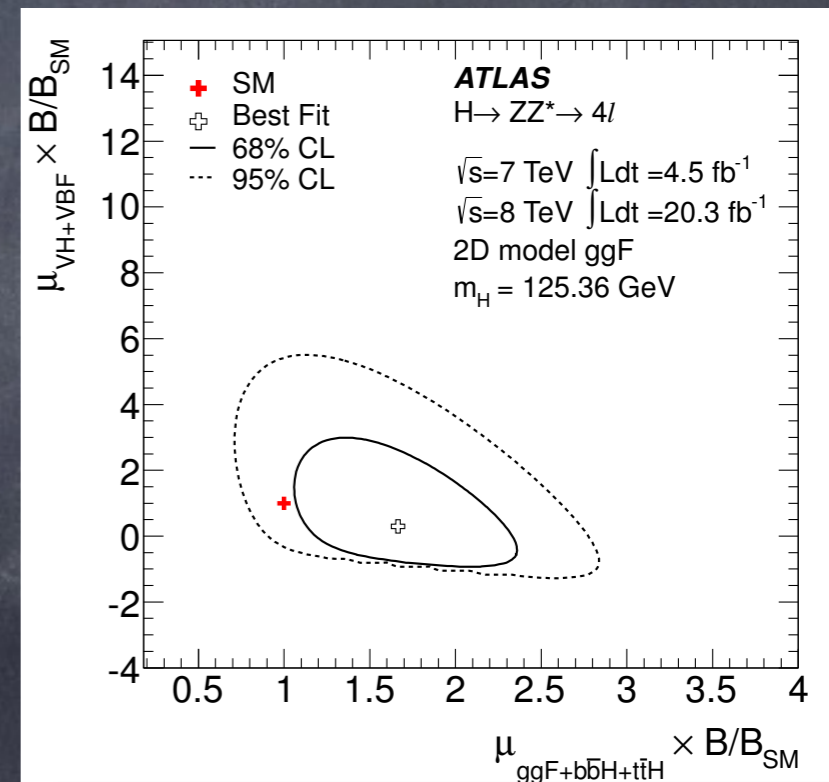
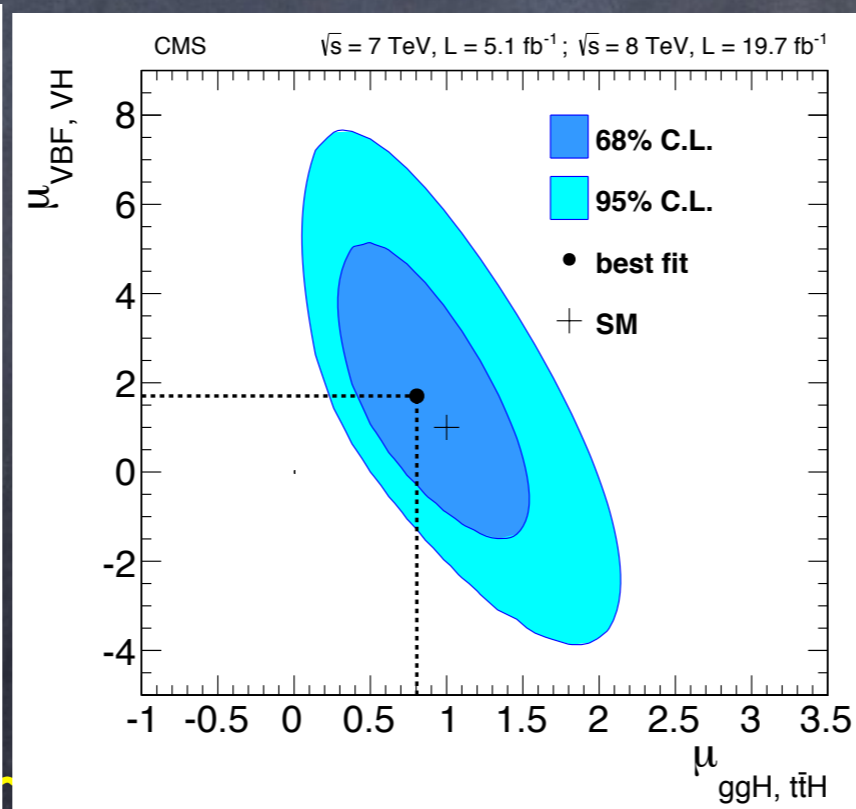
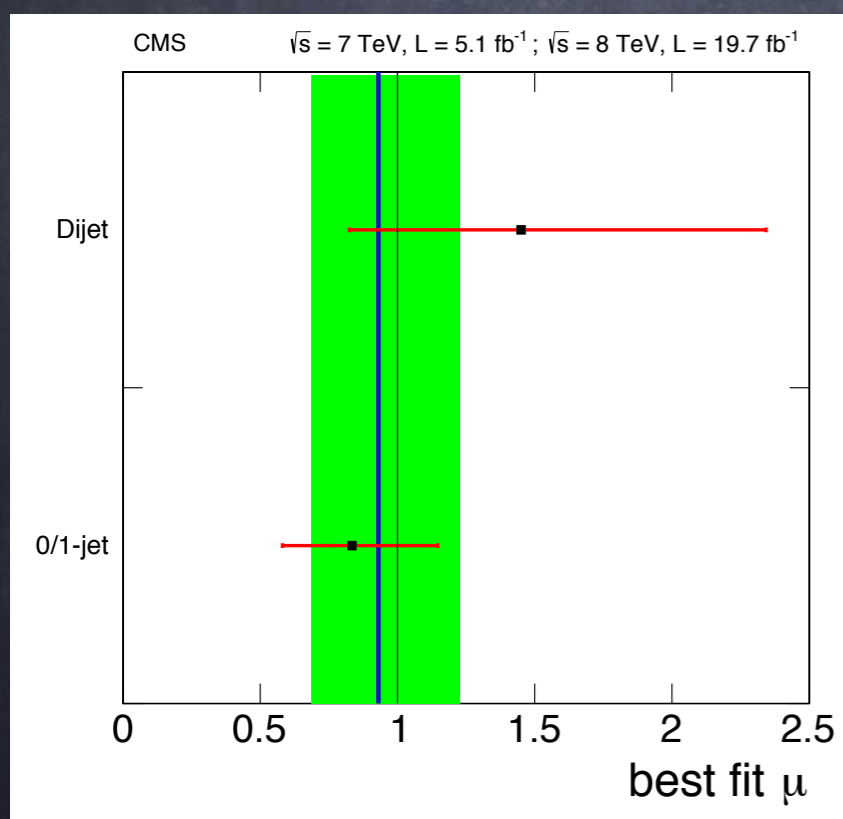
• ATLAS: At $m_H = 125.36$ GeV

$$\mu_{incl.} = 1.44^{+0.34}_{-0.31} (\text{stat})^{+0.21}_{-0.11} (\text{syst})$$

$$\mu_{ggH, t\bar{t}H} = 0.80^{+0.46}_{-0.36} \text{ and } \mu_{VBF, VH} = 1.7^{+2.2}_{-2.1}$$



PRD 91, 012006 (2015)



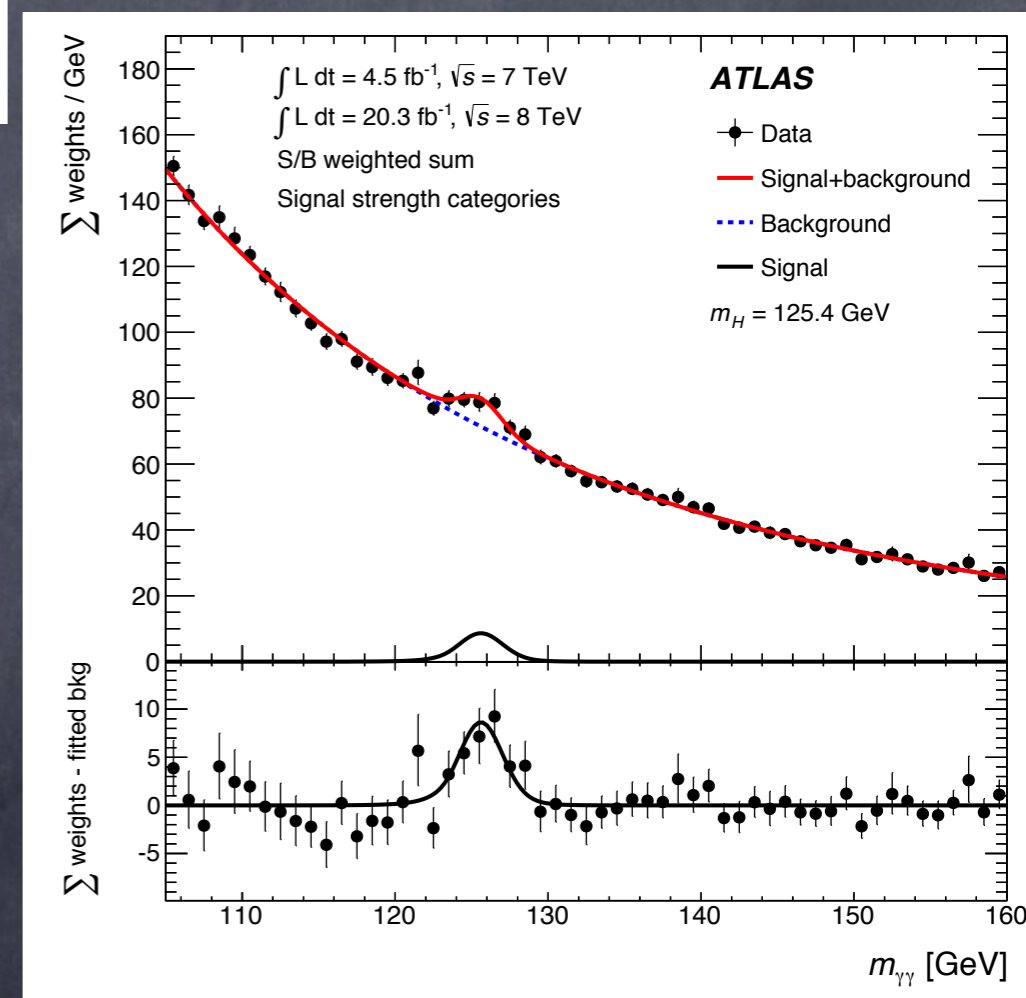
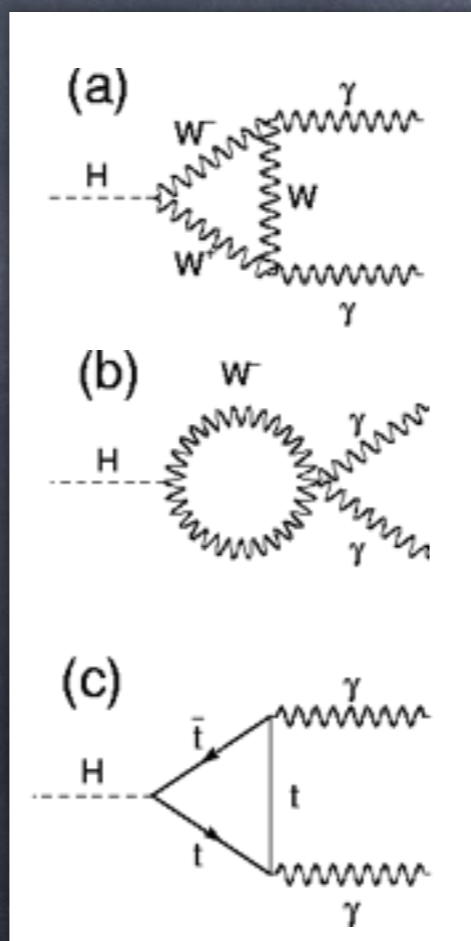
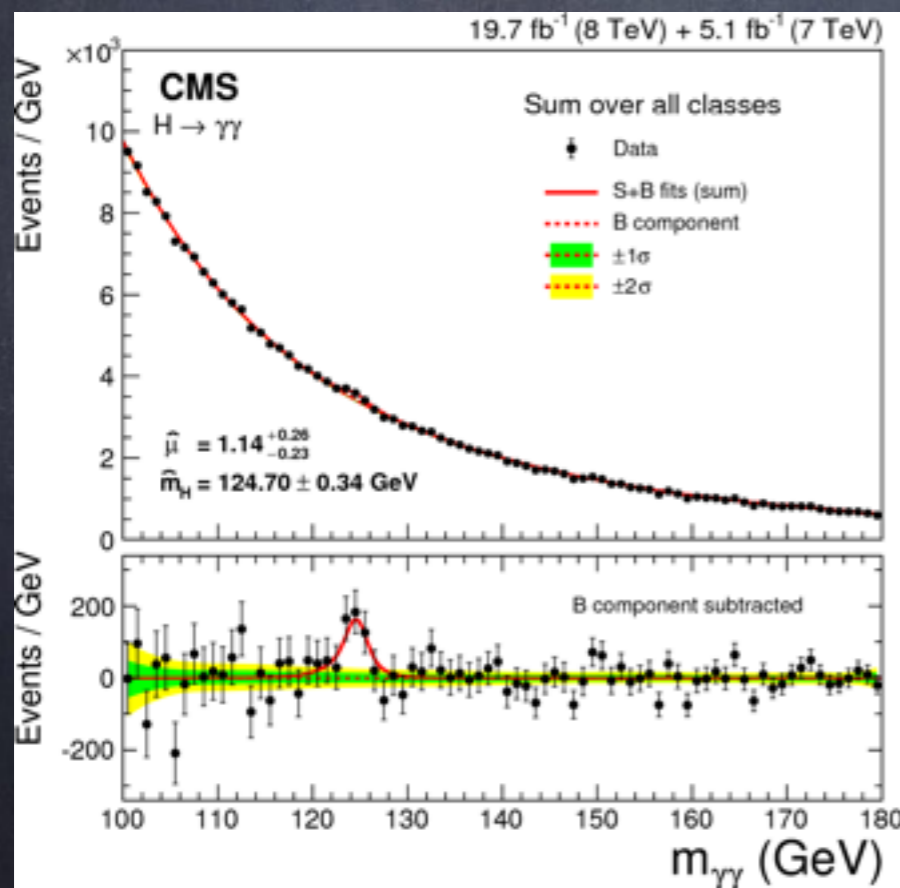
$$\mu_{VBF, VH} = 0.3^{+1.6}_{-0.9}$$

Search for $H \rightarrow \gamma\gamma$

- Within the SM $H \rightarrow \gamma\gamma$ decays allowed through the top/W loops and thus this channel is sensitive to new phenomena
- Event topology is fully reconstructed with very good mass resolution
- Observed signal strength is consistent with SM predictions:

ATLAS: $\mu_{incl.} = 1.17 \pm 0.23(\text{stat})_{-0.08}^{+0.10}(\text{syst})_{-0.08}^{+0.12}(\text{theory})$

CMS: $\mu_{incl.} = 1.14 \pm 0.21(\text{stat})_{-0.05}^{+0.09}(\text{syst})_{-0.09}^{+0.13}(\text{theory})$

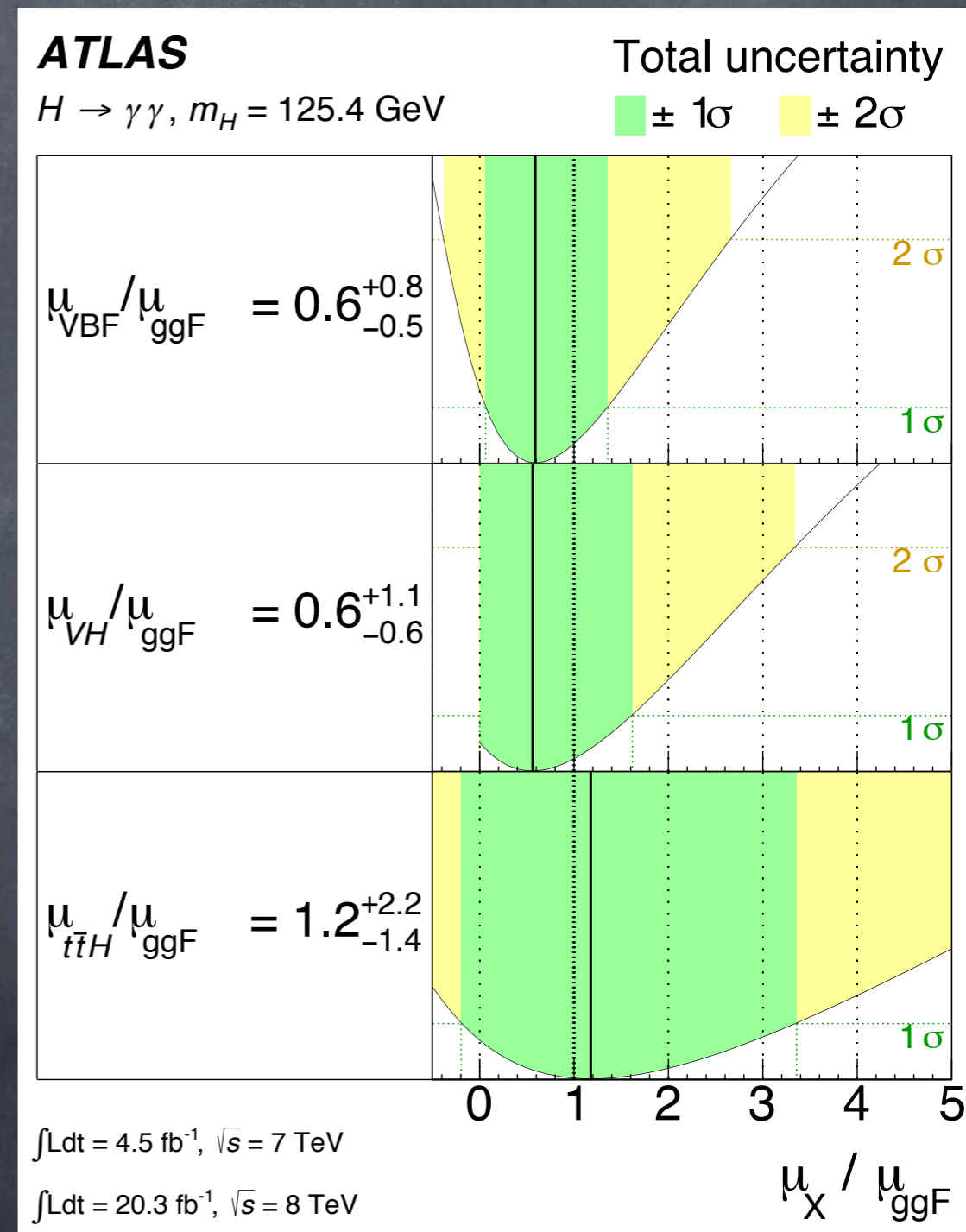
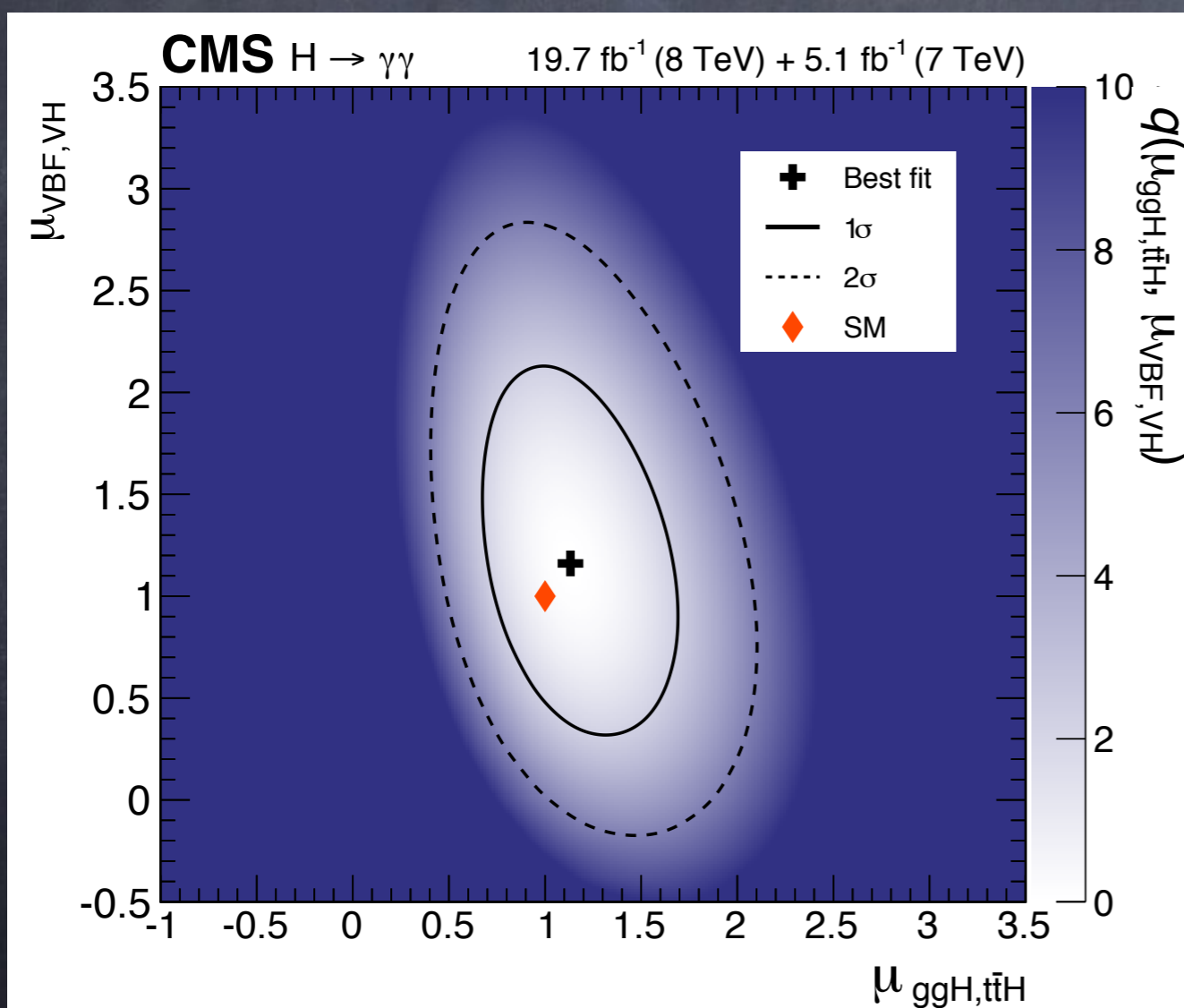


Eur. Phys J C74, 3076 (2014)

PRD 90,112015(2014)

Search for $H \rightarrow \gamma\gamma$ (II)

- Correlation studies between different production modes
- ATLAS: ggF vs VBF, VH and ttH
- CMS ggF+ttH vs VBF+VH

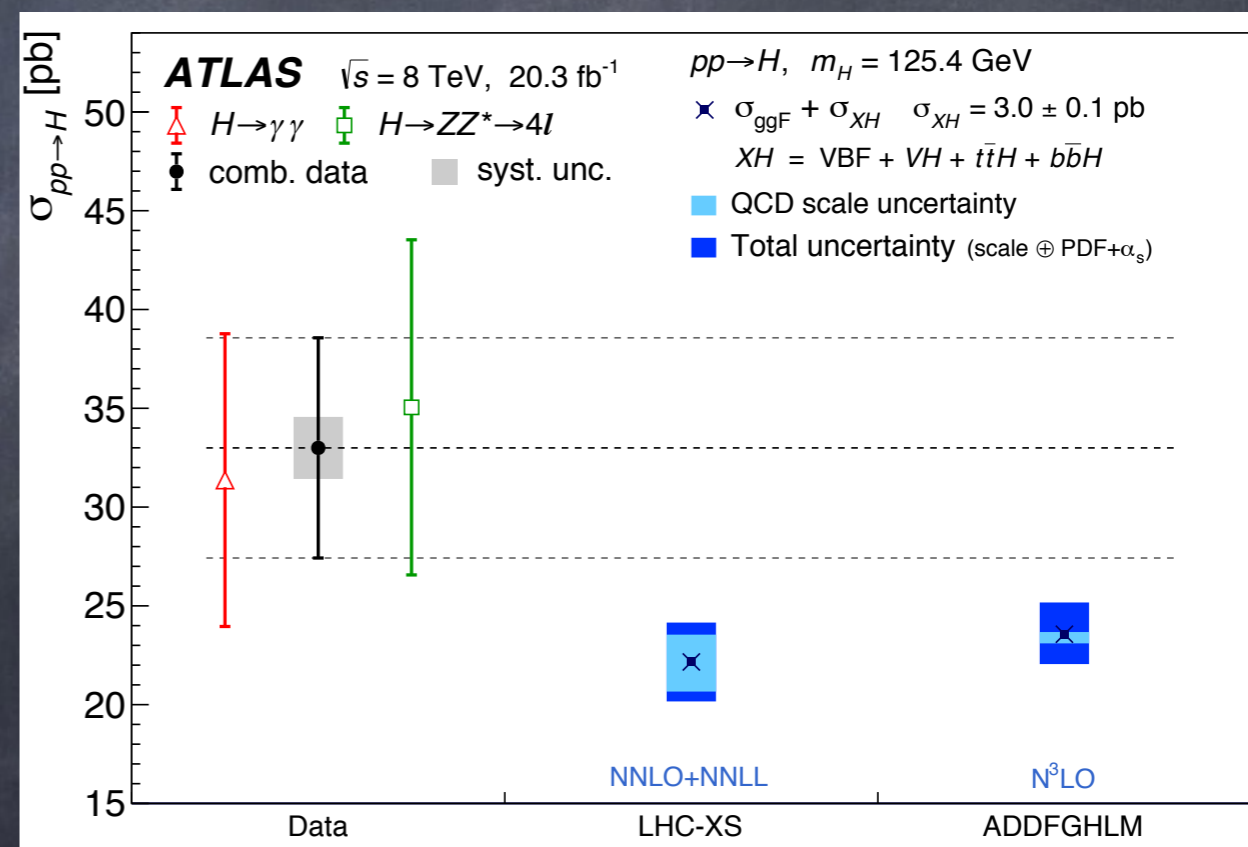
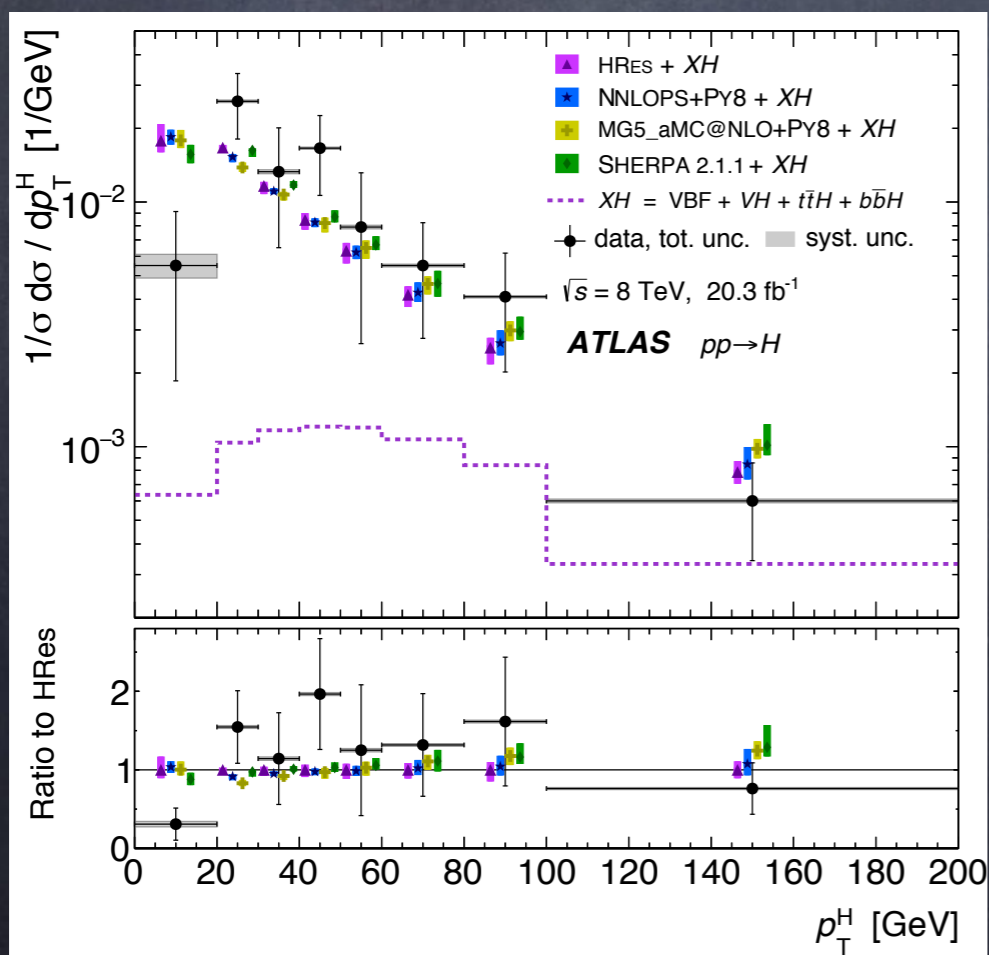


Eur. Phys J C74, 3076 (2014)

PRD 90,112015(2014)

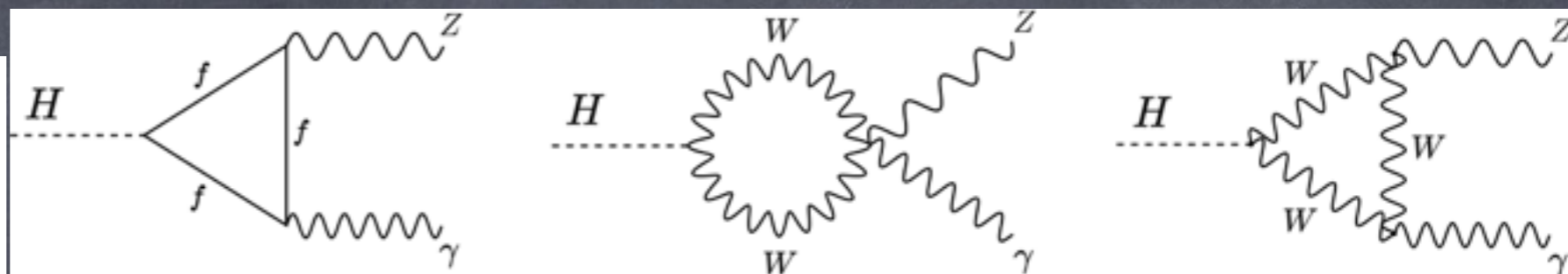
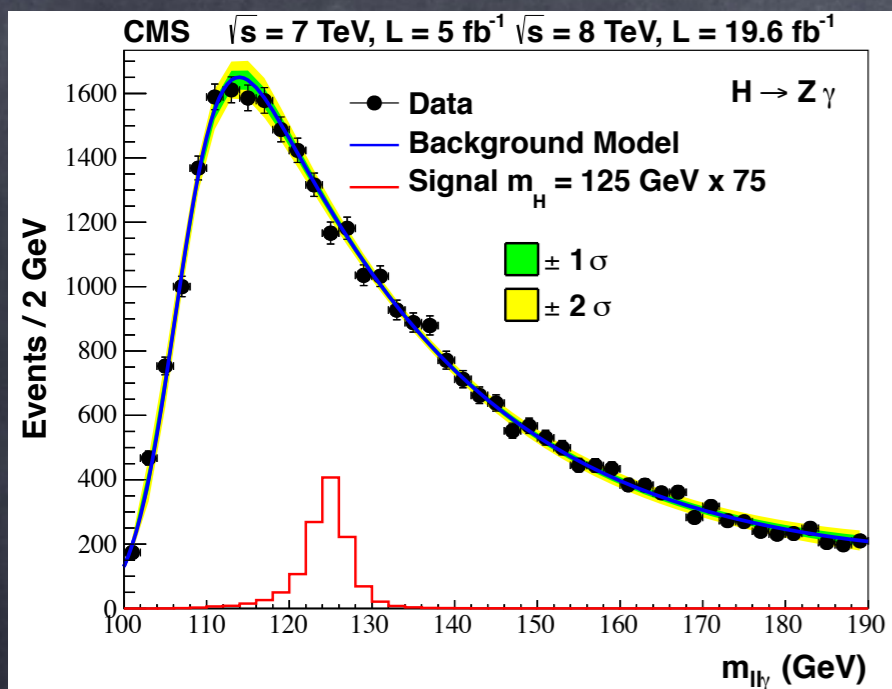
Total & differential cross-section

- Total cross-section measurement using $H \rightarrow ZZ$ and $H \rightarrow \gamma\gamma$ events
 - $H \rightarrow ZZ$: $35.0 \pm 8.4(\text{stat}) \pm 1.8(\text{syst})$ pb
 - $H \rightarrow \gamma\gamma$: $31.4 \pm 7.2(\text{stat}) \pm 1.6(\text{syst})$ pb
 - Total: $33.0 \pm 5.3(\text{stat}) \pm 1.6(\text{syst})$ pb
- Differential cross-section as functions of p_T^H , $|\eta^H|$, p_T^{jets} & N_{jets}



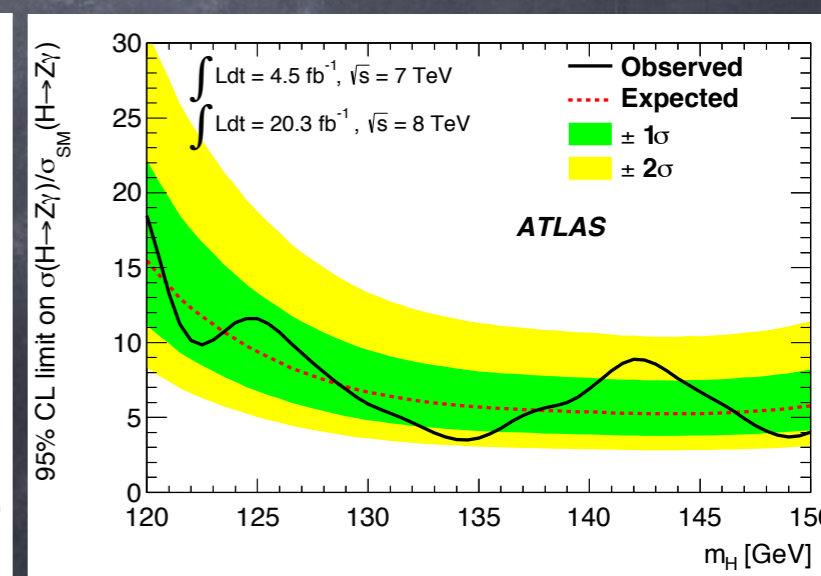
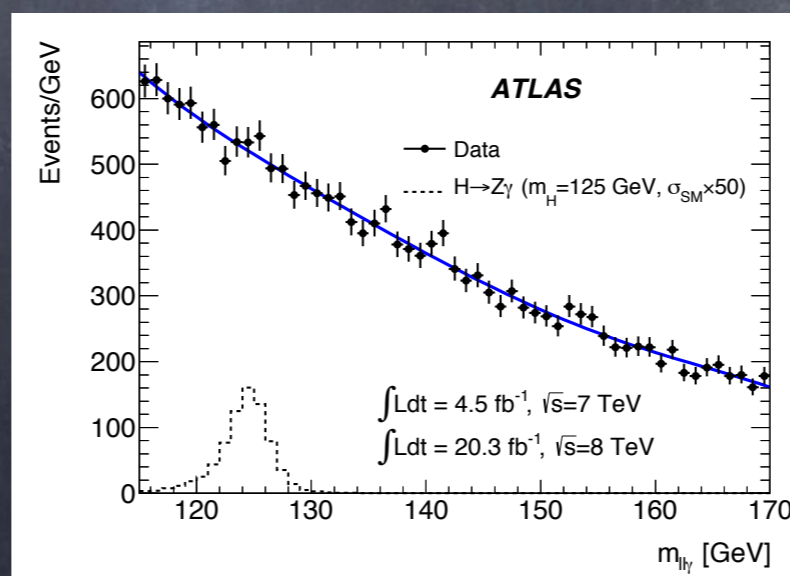
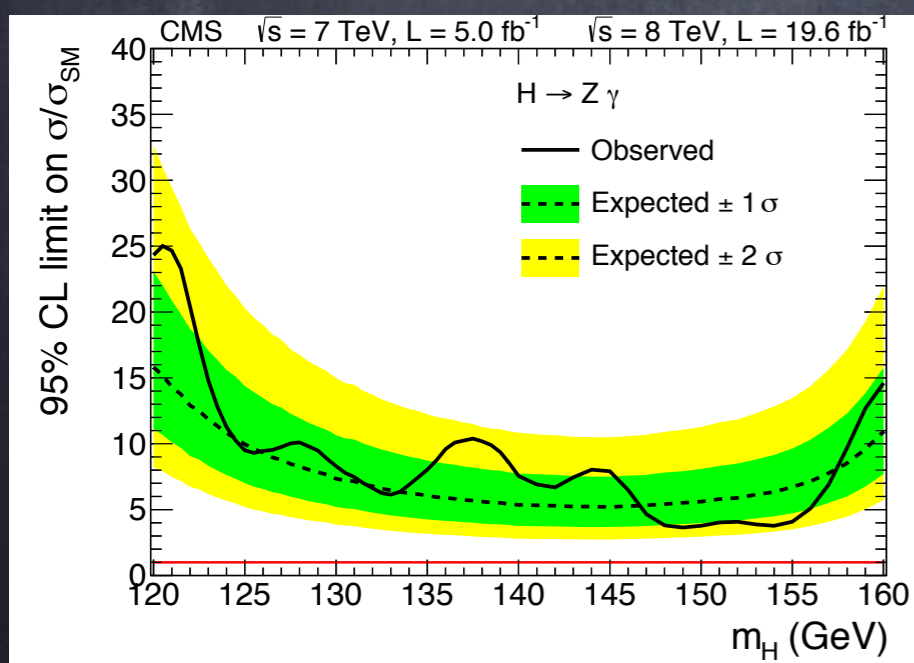
arXiv:1504.05833

Search for $H \rightarrow Z\gamma$



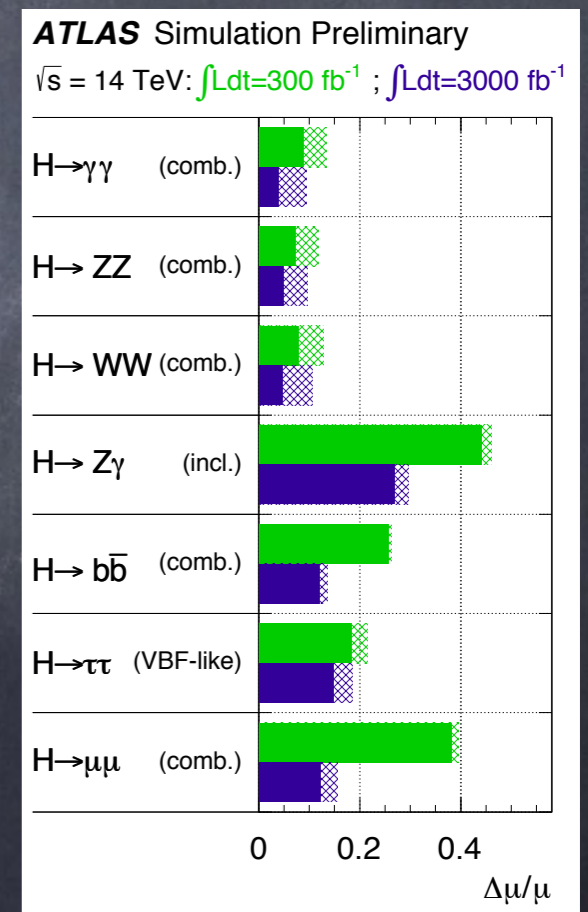
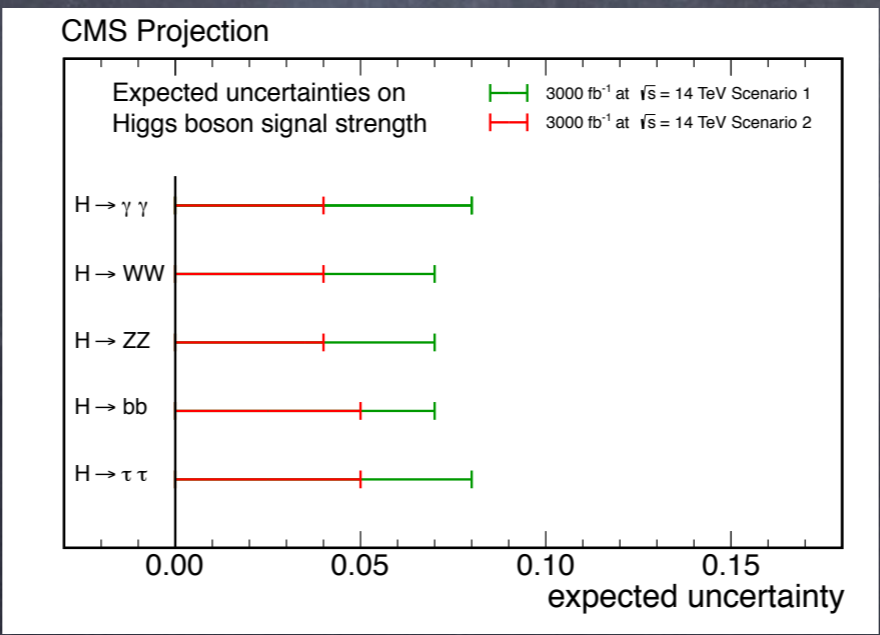
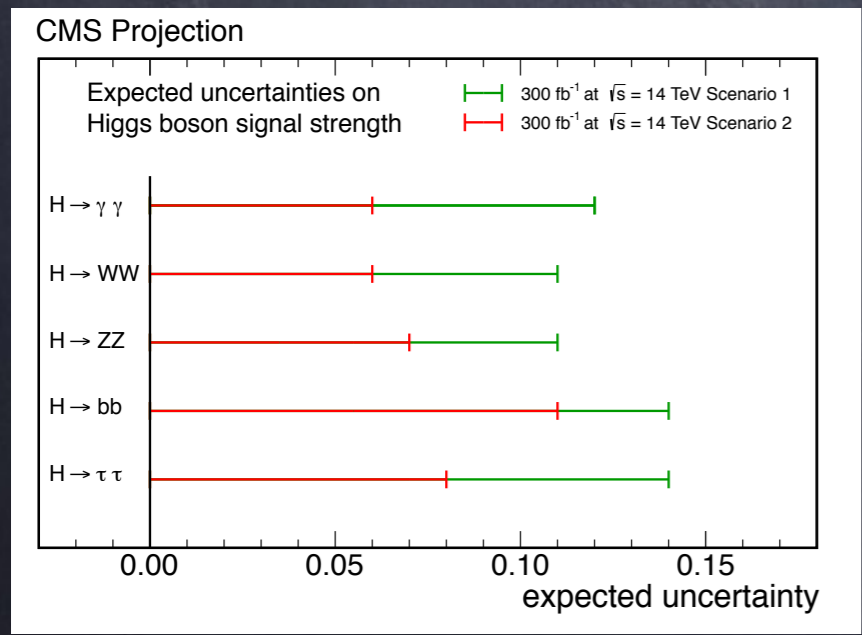
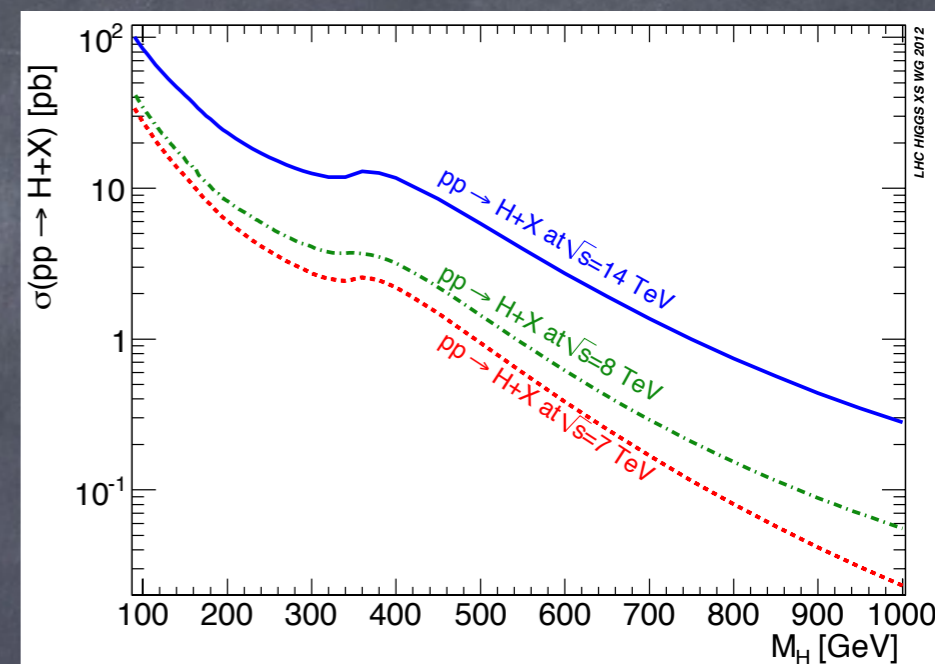
- Potential search channel for probing BSM physics through loop diagrams
- No statistically significant excess observed
- ATLAS limits (@95%CL): $\mu < 11$ for $m_H = 125 \text{ GeV}$
- CMS limits (@95%CL): $\mu < 9.5$ for $m_H = 125 \text{ GeV}$

[CMS-HIG-13-006/arXiv:1307.5515](https://arxiv.org/abs/1307.5515)



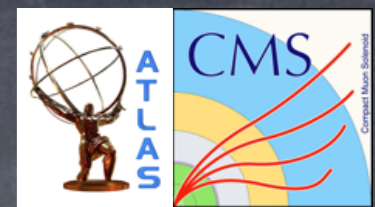
[PLB 732C, 8\(2014\)/arXiv:1402.3051](https://arxiv.org/abs/1402.3051)

- During LHC Run II, at higher center of mass energy ($\sqrt{s}=13$ TeV), the Higgs production cross-sections would be enhanced by a factor of 2 in ggF, VBF and VH.
- The projected integrated luminosity to be accumulated during Run II would increase the precision of Higgs results.





Summary & Outlook

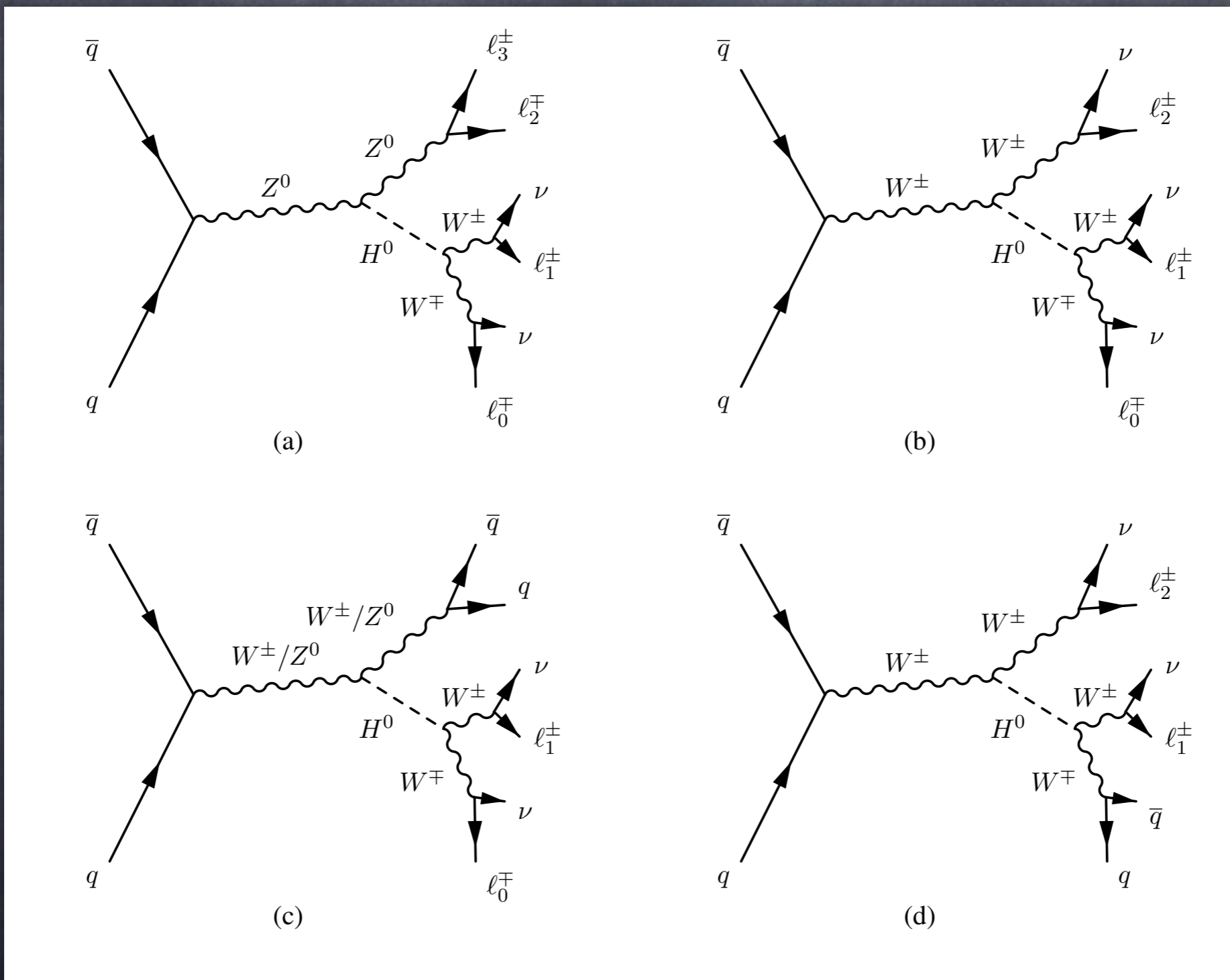


- At the LHC, the VBF/VH Higgs production with subsequent decays into the bosons (WW , ZZ , $\gamma\gamma$) provide excellent opportunity to study various properties of the Higgs.
- ATLAS and CMS have performed extensive searches for the SM Higgs using Run I dataset.
- The observed signal strengths in $ggF/VH/VBF$ are consistent with the SM expectations.
- The differential and total production cross section for the Higgs boson are measured using $H \rightarrow \gamma\gamma$ and $H \rightarrow ZZ$ decays.
- LHC Run II has just begun and all the Higgs results would be superseded with the Run II results; associated production of Higgs would have much better sensitivity.



Extras

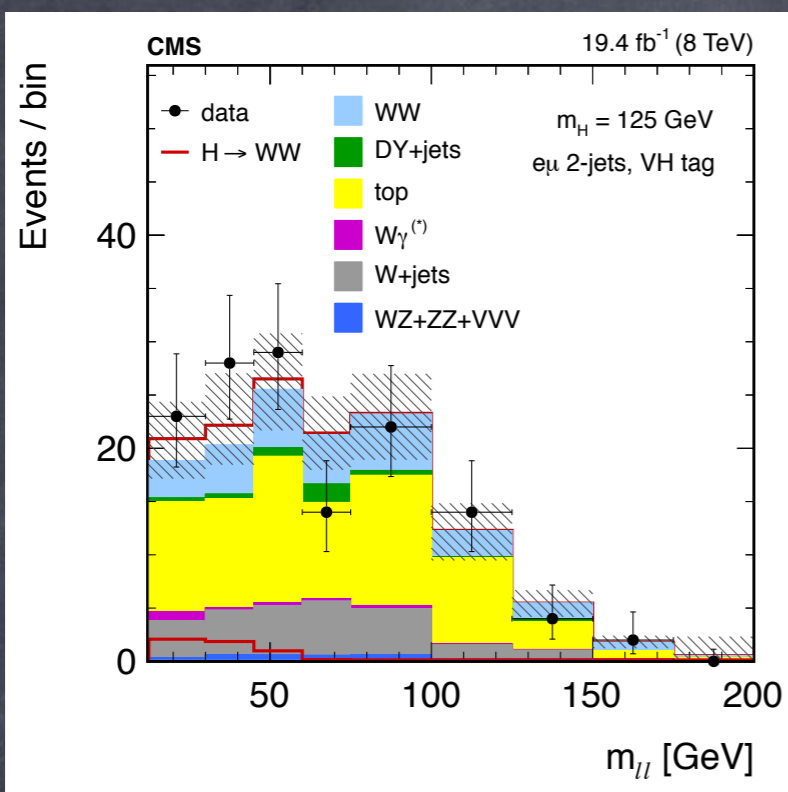
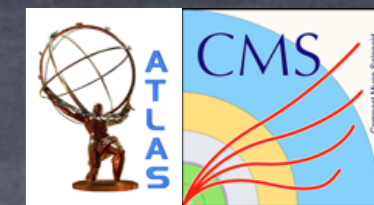
VH(\rightarrow WW)



ATLAS-CONF-2015-005



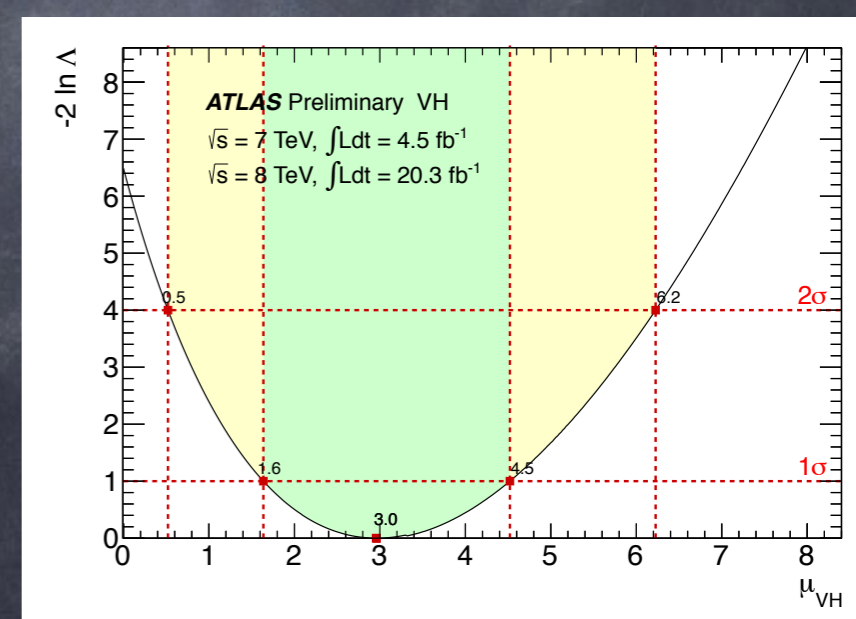
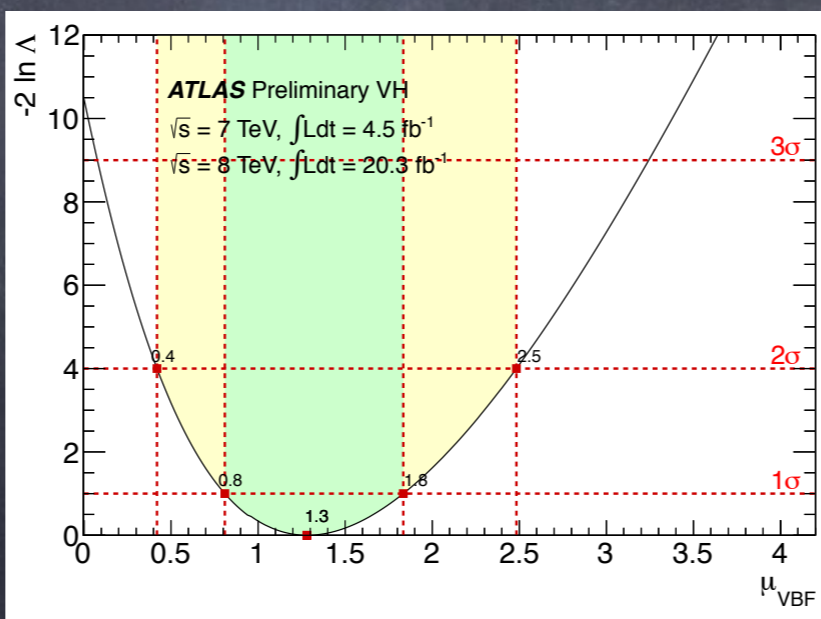
VBF/VH(\rightarrow WW)



VH analysis $m_H = 125$ GeV	95% CL limits on σ/σ_{SM}		Significance		σ/σ_{SM}
	expected / observed		expected / observed		observed
Counting analysis (default)	4.1 / 4.5		0.6 / 0.2 sd		$0.40^{+2.03}_{-1.93}$
Shape-based	4.0 / 4.7		0.6 / 0.4 sd		$0.73^{+2.04}_{-1.85}$

CMS-HIG-13-023/arXiv:1312.1129

Category	Signal significance Z_0		
	Exp. Z_0	Obs. Z_0	Obs. Z_0
ggF	4.4	4.2	4.2
VBF	2.6	3.2	3.2
VH	0.93	2.5	2.5
WH only	0.77	1.4	1.4
ZH only	0.30	2.0	2.0
ggF+VBF+VH	5.9	6.5	6.5

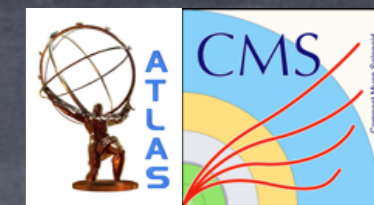


ATLAS-CONF-2015-005

Backup-II

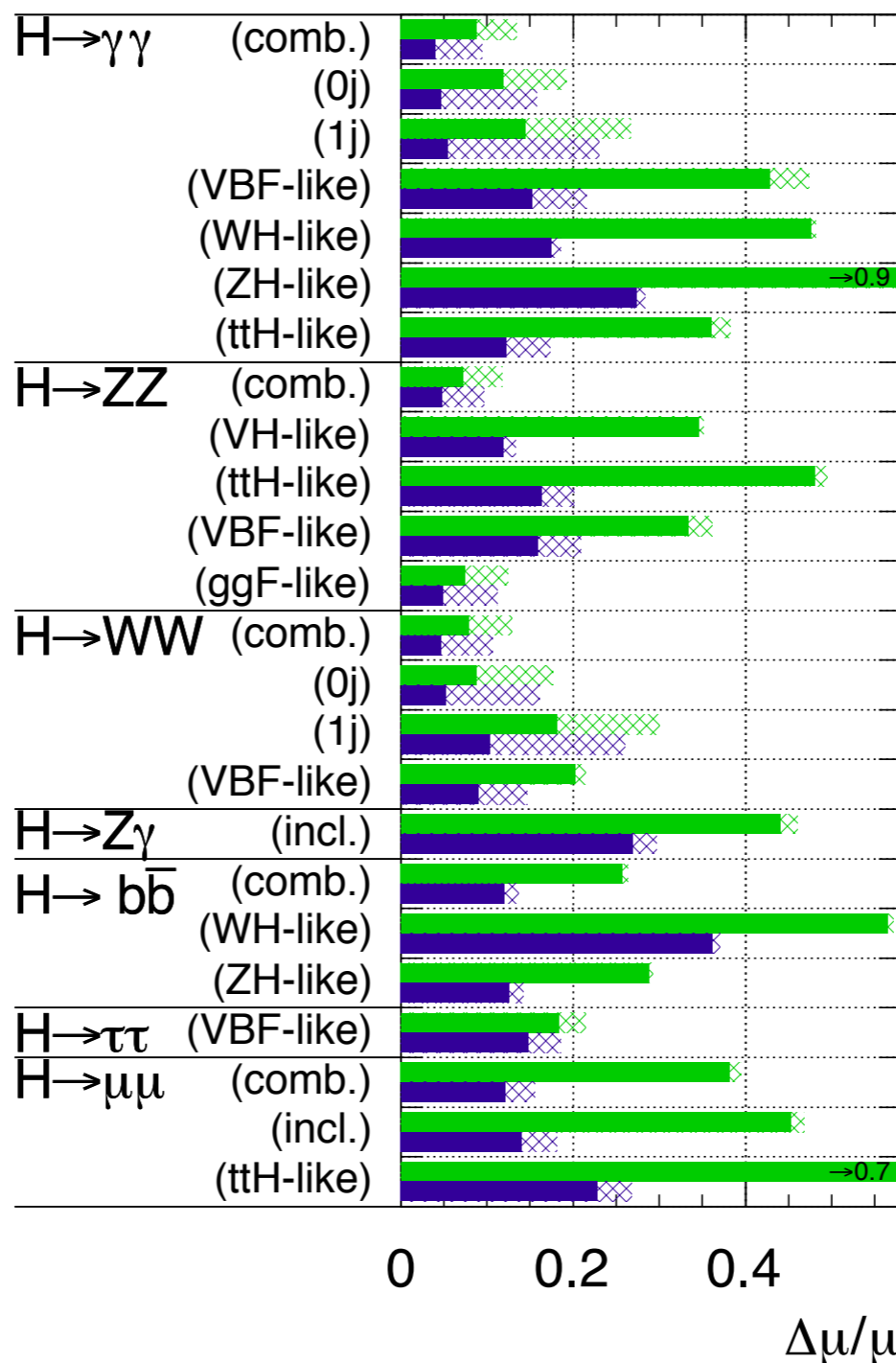


Run II Perspective



ATLAS Simulation Preliminary

$\sqrt{s} = 14$ TeV: $\int L dt = 300 \text{ fb}^{-1}$; $\int L dt = 3000 \text{ fb}^{-1}$



ATL-PHYS-PUB-2014-016