Project from ATLAS-ACC(SDU/USTC)-LAL for 2016

Project title

- Study of the low mass Higgs boson and search for heavy Higgs boson in the WW channel

Members

French group			Chinese group		
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Results of the project

Publications in 2015:

1. Observation and measurement of Higgs boson decays to $WW*$ with the ATLAS detector, Phys. Rev. D92 (2015) 012006

2. Determination of spin and parity of the Higgs boson in the $WW^* \rightarrow e\nu\nu\mu$ channel with the ATLAS detector, Eur. Phys. J. C75 (2015) 231

3. Study of the spin and parity of the Higgs boson in diboson decays with the ATLAS detector, Eur. Phys. J. C75 (2015) 476

4. Constraints on the off-shell Higgs boson signal strength in the high-mass ZZ and WW final states with the ATLAS detector, Eur. Phys. J. C75 (2015) 335

5. Search for high-mass Higgs boson decaying to a W boson pair in pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector, JHEP 01 (2016) 032.

CONF Note for Moriond 2016

- Search for a high-mass Higgs boson decaying to a pair of W bosons in pp collisions at √s=13 TeV with the ATLAS detector
  - ATLAS-COM-CONF-2016-018
  - Results reported to Moriond QCD

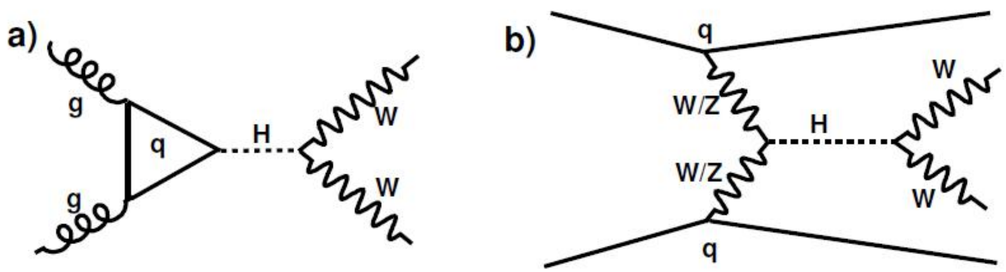
- Introduction
- Results
- Conclusion

Introduction

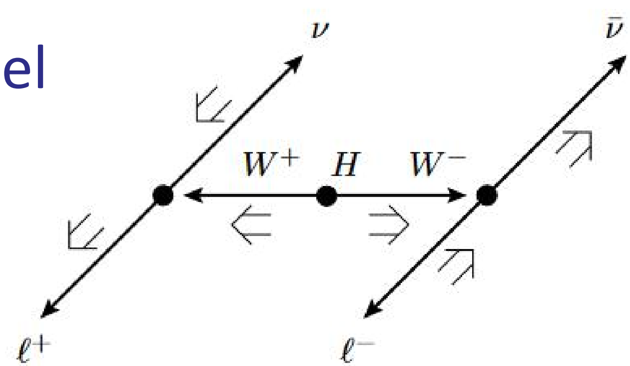
- Motivation: search for a potential extension of the Standard Model(SM) with an extended Higgs sector
- Scenarios in our study:
  - SM-like heavy Higgs with a narrow or large width
- Higgs production modes in our study:

a) ggF

b) VBF



- The analysis channel
  - H→WW→lvlv

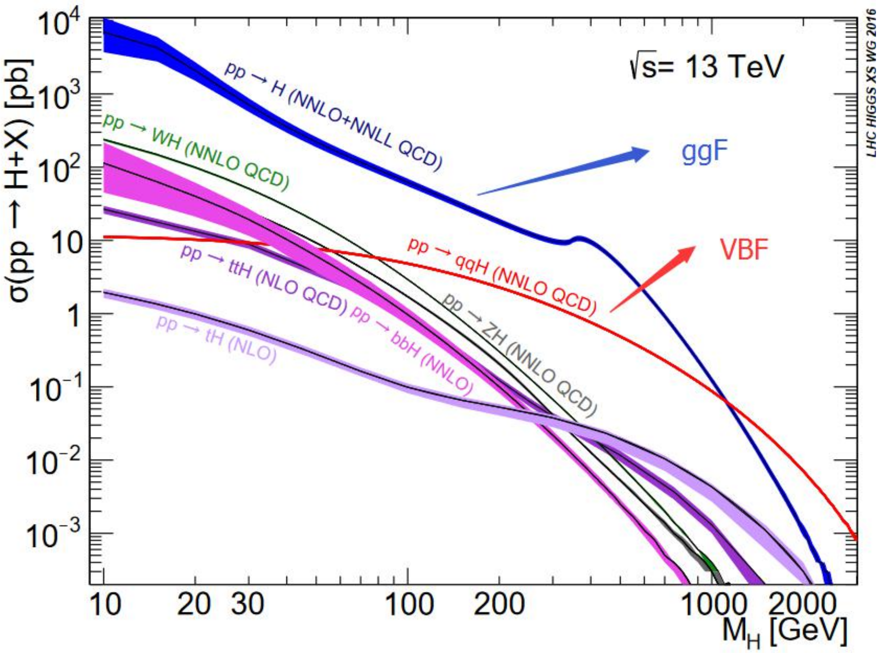


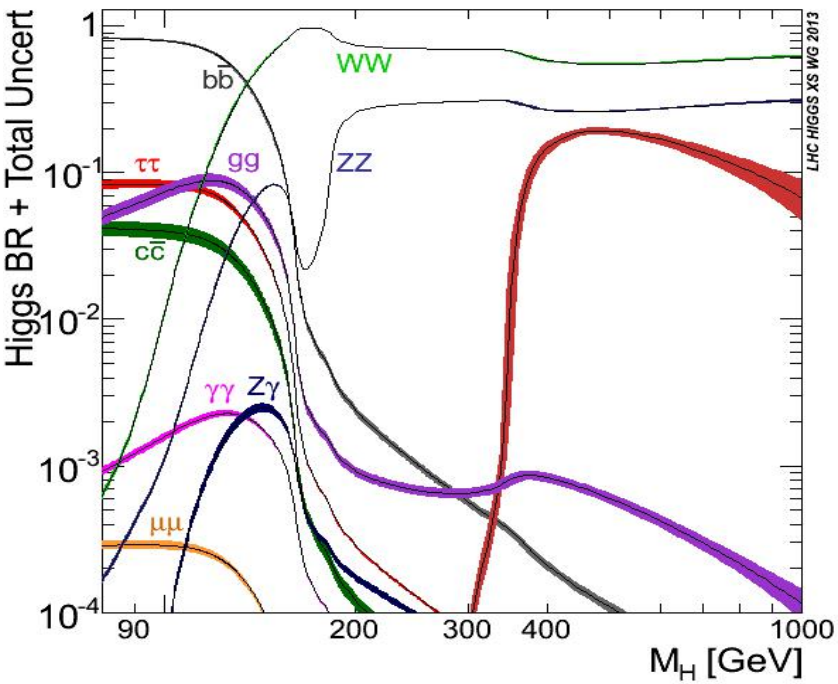
Introduction

- Run 1 v.s Run 2 (results in this talk based on Run 2)

Data from LHC	Center of Mass Energy	Integrated luminosity
Run 1 (2011 - 2012)	7TeV, 8TeV	25 fb^{-1}
Run 2 (2015 - now)	13TeV	3.2 fb^{-1}

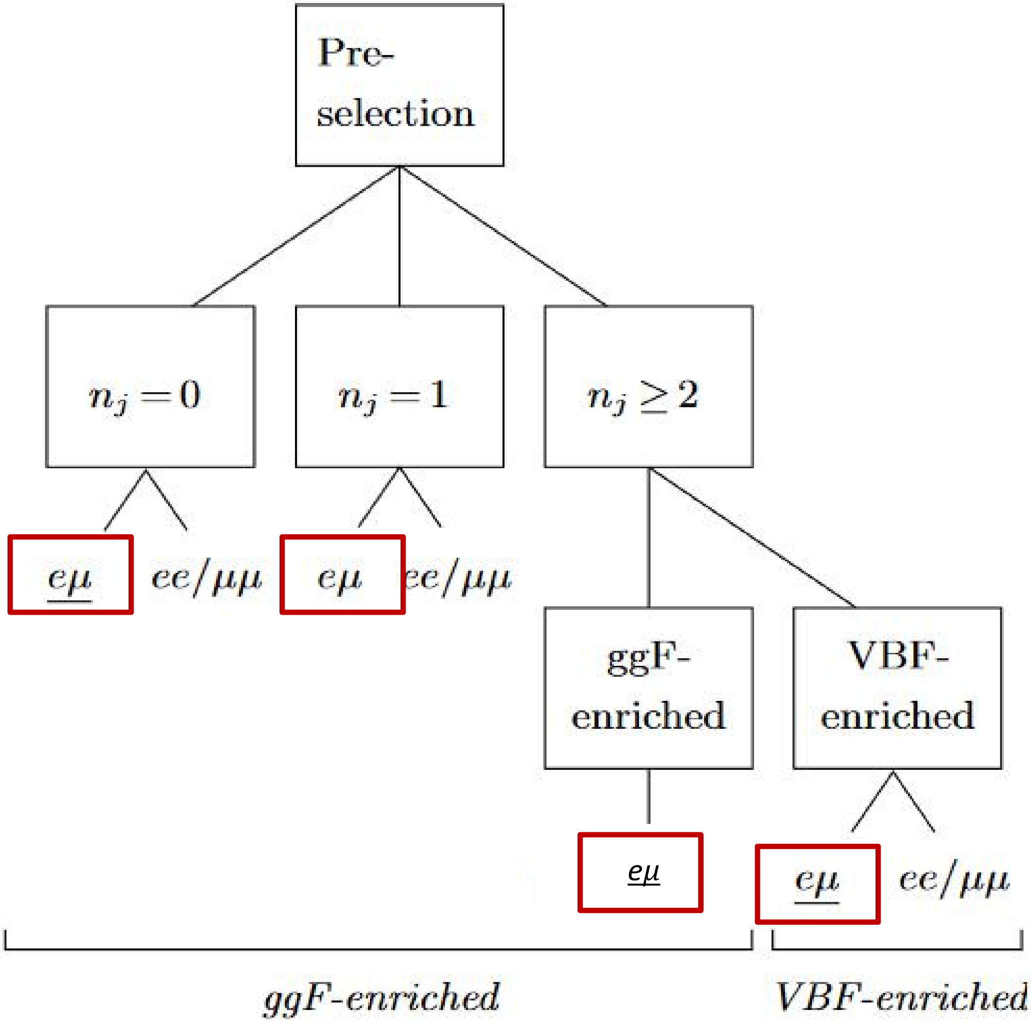
- Higgs production cross section and branching ratio





Introduction

- Jet multiplicity categories



- Background strongly dependent on the jet categories
- μμ, ee not considered for the moment

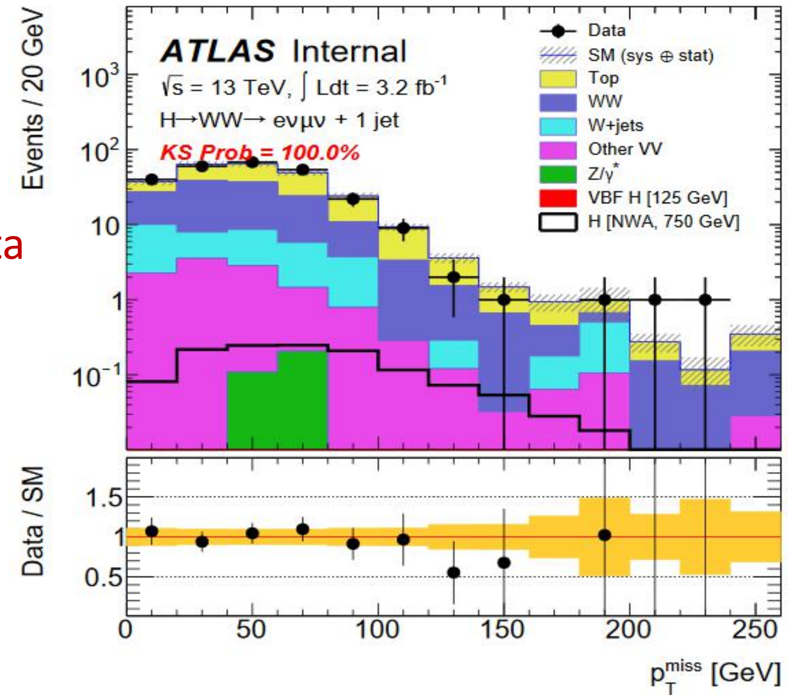
Introduction

■ Transverse missing momentum:

Negative vectorial sum of the transverse momenta

➢ E_T^{miss}: Based on calorimeter objects

➢ p_T^{miss}: Based on charged tracks



■ Transverse invariant mass:

$$M_T = \sqrt{(E_T^{ll} + E_T^{miss})^2 - |\mathbf{p}_T^{ll} + \mathbf{E}_T^{miss}|^2}$$

→ Discriminating variable

$$where \quad E_T^{ll} = \sqrt{|\mathbf{p}_T^{ll}| + m_{ll}^2}$$

Introduction

- Event selection: re-optimized
  - Developed a simple and general optimization procedure
  - Described in an internal ATLAS note

Preselection cuts: $e^\pm\mu^\mp$, $\mu^\pm e^\mp$, $p_T^{lead} > 25$ GeV, $p_T^{sublead} > 15$ GeV, third lepton veto

	Signal region			WW control region		Top-quark control region	
	$N_{jet} = 0$	$N_{jet} = 1$	$N_{jet} \geq 2$	$N_{jet} = 0$	$N_{jet} = 1$	$N_{jet} = 1$	$N_{jet} \geq 2$
$\lvert\Delta\eta_{\ell\ell}\rvert$	< 1.8	< 1.8	< 1.8	> 1.8	> 1.8		
$N_{b\text{-jet}}$		$= 0$	$= 0$		$= 0$	$= 1$	$= 1$
p_T^{lead}	> 120 GeV	> 120 GeV	> 120 GeV	> 30 GeV	> 30 GeV		
$p_T^{sublead}$		> 40 GeV	> 40 GeV	> 30 GeV	> 30 GeV		
p_T^{miss}	> 40 GeV	> 40 GeV		> 20 GeV	> 20 GeV		
$m_{\ell\ell}$	> 100 GeV	> 100 GeV	> 150 GeV	> 100 GeV	> 100 GeV	> 100 GeV	> 150 GeV
m_{jj}			> 650 GeV				
$\lvert\Delta y_{jj}\rvert$			> 4.25				

- Background estimation
  - WW, Top: main backgrounds → estimated from control regions
  - W+jets: not well simulated and low statistics → data-driven estimation
  - Z+jets, Diboson(NonWW), H125: small contribution → MC prediction

Results: Event yields

- Event yields for Njet = 0, 1

	N_{jet} = 0 SR	N_{jet} = 1 SR	N_{jet} = 0 WW CR	N_{jet} = 1 WW CR	N_{jet} = 1 Top CR
WW	45 ± 4	47 ± 7	177 ± 17	99 ± 19	29 ± 10
Top	42 ± 3	73 ± 6	40 ± 4	100 ± 10	1485 ± 40
Z/γ^* + W+jets + VV	6.0 ± 2.3	7.1 ± 2.5	17 ± 8	17 ± 9	15 ± 7
Backgrounds	93 ± 4	127 ± 6	233 ± 14	216 ± 13	1530 ± 40
Data	88	121	236	219	1532

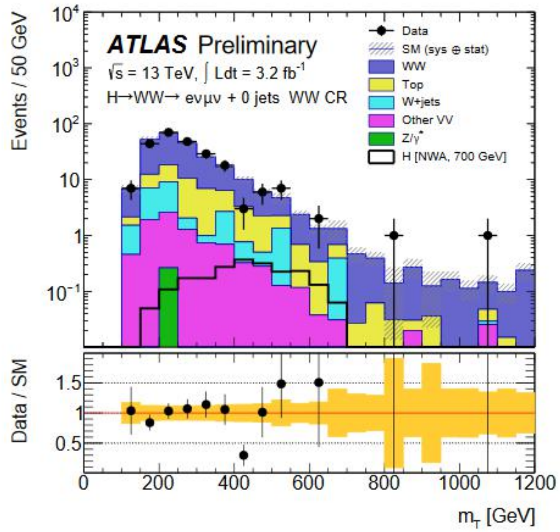
- Event yields for Njet ≥ 2

	N_{jet} ≥ 2 SR	N_{jet} ≥ 2 Top CR
WW	2.2 ± 0.4	28 ± 6
Top	6.5 ± 1.7	2520 ± 50
Z/γ^* + W+jets + VV	0.8 ± 0.3	22 ± 11
Backgrounds	9.5 ± 1.8	2570 ± 50
Data	11	2570

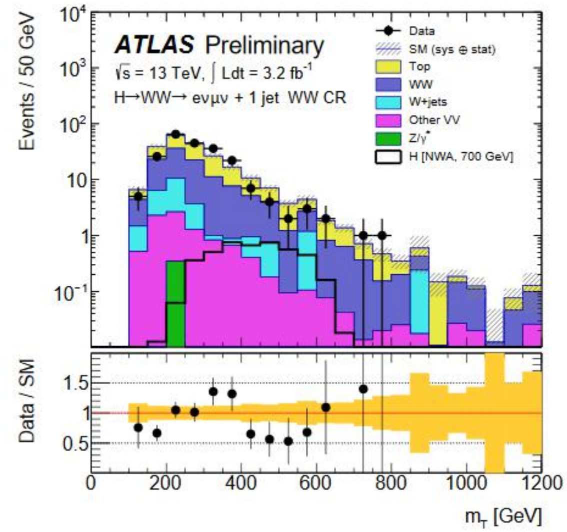
✓ statistical and systematic uncertainties combined

Results: plots in control regions (CR)

- **WW CR**
  - a) $N_{jet} = 0$
  - b) $N_{jet} = 1$

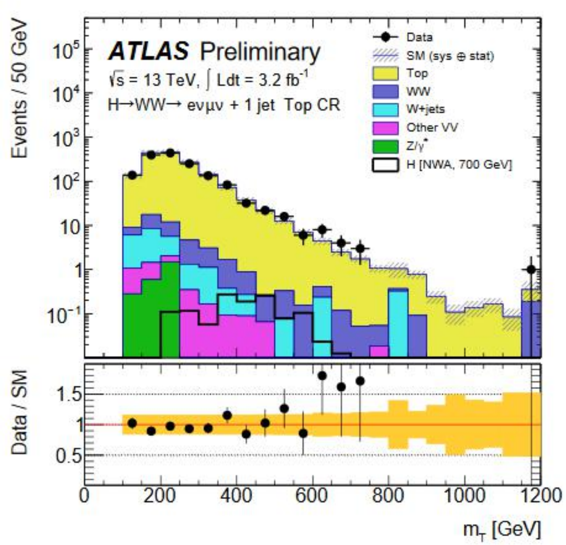


(a) WW CR $N_{jet} = 0$

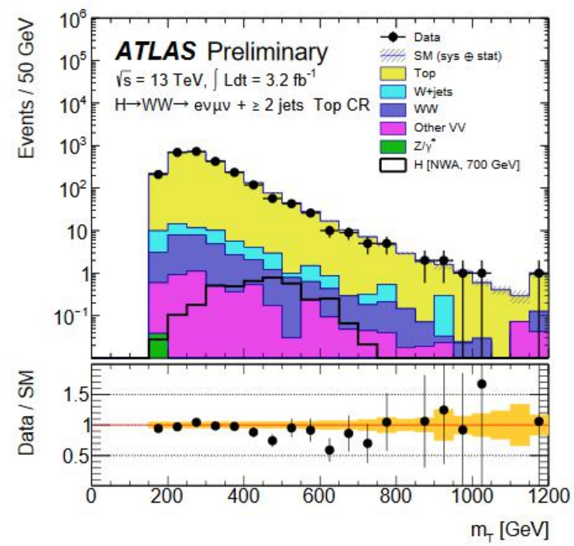


(b) WW CR $N_{jet} = 1$

- **Top CR**
  - a) $N_{jet} = 1$
  - b) $N_{jet} \geq 2$



(a) Top CR $N_{jet} = 1$



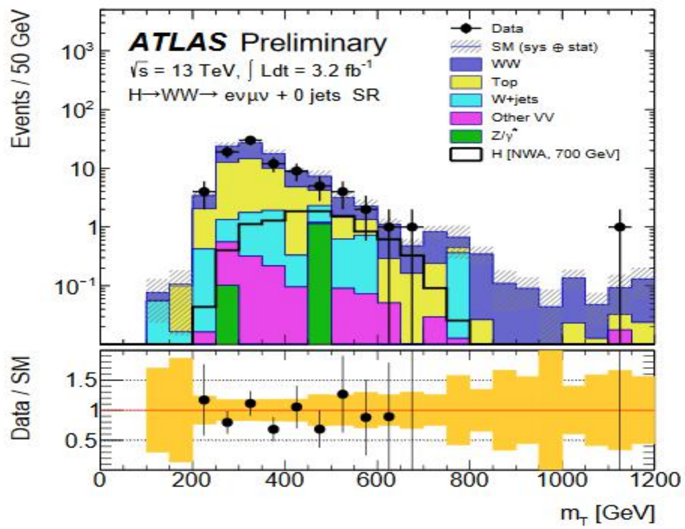
(b) Top CR $N_{jet} \geq 2$

Results: plots in signal regions (SR)

- NWA, with m_H = 700 GeV shown as signal

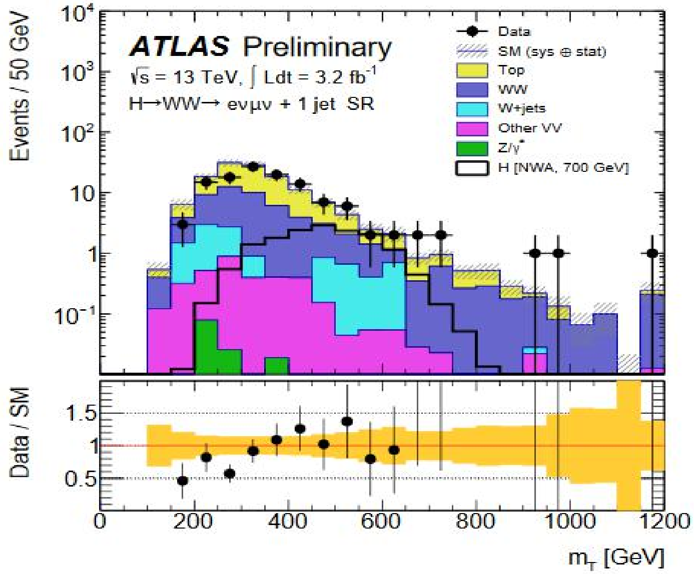
➢ SR

$N_{jet} = 0$



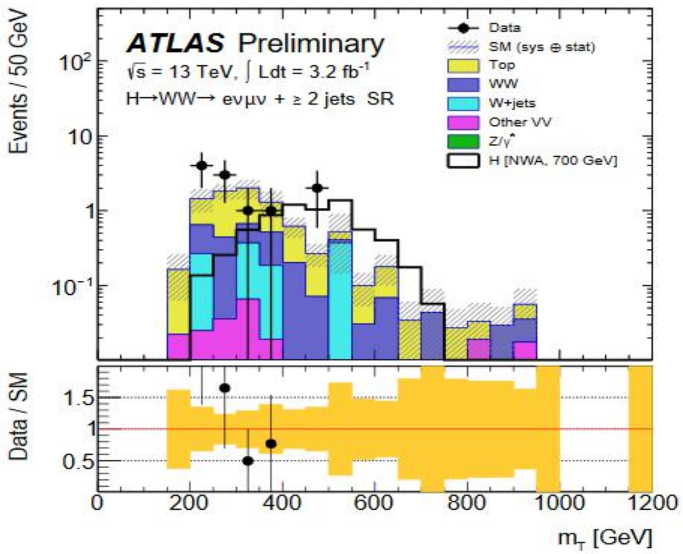
➢ SR

$N_{jet} = 1$



➢ SR

$N_{jet} \geq 2$



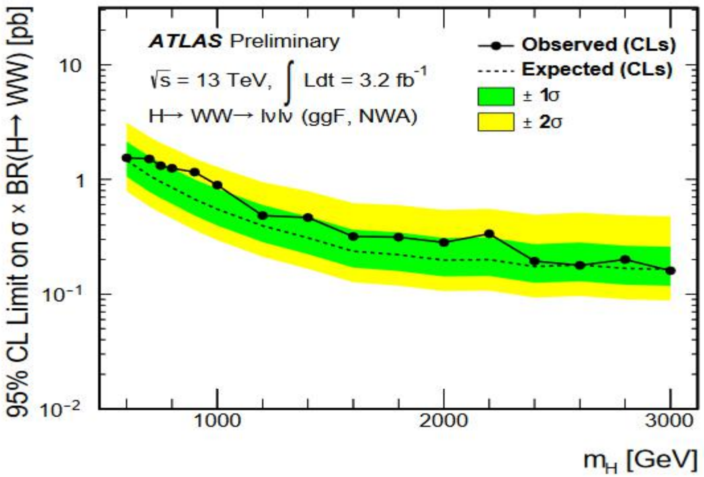
→ No significant excess

ggF scaled to : $\sigma_H \times BR(H \rightarrow WW) = 1\,\text{pb}$

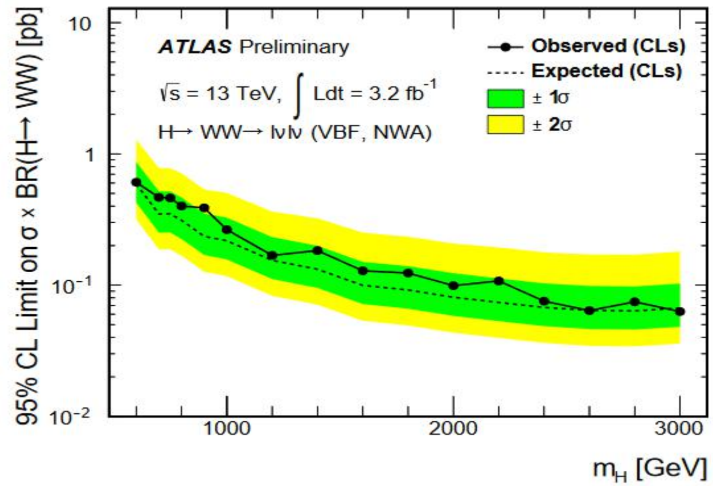
VBF scaled to have the same relative fraction as SM prediction

Results: upper limits

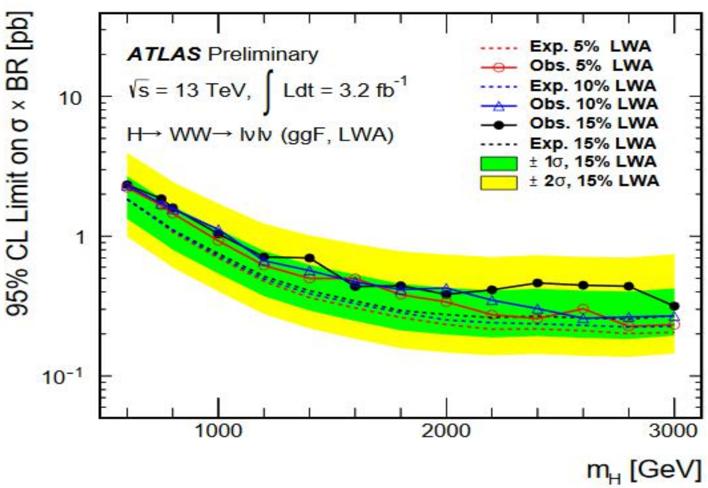
- 95% CL upper limit on $\sigma_H \times BR(H \rightarrow WW)$



(a) NWA, ggF



(b) NWA, VBF



(c) LWA, ggF

No strong evidence for an excess around 750 GeV

NWA: SM-like Higgs with narrow width

LWA: wih large width

Conclusion

- A search for heavy Higgs boson performed in the H→WW→lvlv decay channels at 13 TeV with 3.2 fb^{-1} data
- No significant excess found between 600 GeV and 3 TeV
- 95% CL upper limits on $\sigma_H \times BR(H \rightarrow WW)$ shown for two SM-like Higgs models with a narrow or large width
- Compared to Run 1, the limits extend well from 1.5 TeV to 3 TeV
- Next plan:

  Continue this search with the forthcoming 2016 data

BACKUP

Triggers

Single lepton triggers used in this study for the moment

The single-lepton trigger efficiencies are approximately 70% for muons with $|\eta| < 1.05$, 90% for muons in the range $1.05 < |\eta| < 2.40$, and $\geq 90\%$ for electrons in the range $|\eta| < 2.40$.

Table 1: The minimum transverse momentum (p_T) requirements used at the different levels of the trigger. Letters "m" and "l" next to the threshold value stand for the medium and loose electron identification requirement, respectively. Letter "i" indicates an isolation requirement that is less restrictive than the isolation requirement used in the offline selection. The single-lepton trigger with higher-p_T thresholds are more efficient at high lepton p_T than the lower-p_T triggers because of this isolation requirement.

Lepton	Level-1 trigger	High-level trigger
e	20 GeV	24m OR 60m OR 120l GeV
μ	15 GeV	20i OR 50 GeV

Object reconstruction

- Primary vertex (PV) = 1
  - ≥ 2 associated tracks with p_T > 400 MeV
  - if > 1 vertex meet the requirement above, the largest track $\sum p_T^2$ chosen as PV
- Electron
  - MediumLH for pT > 25 GeV or TightLH for 15 < pT < 25GeV
  - $|\eta| < 2.47$, except for $1.37 < |\eta| < 1.52$
- Muon
  - Medium for pT > 25 GeV or Tight for 15 < pT < 25GeV
  - $|\eta| < 2.5$
- Jet
  - p_T > 25 GeV for $|\eta| < 2.4$, and p_T > 30 GeV for $2.4 < |\eta| < 4.5$
  - JVT > 0.64 for p_T < 50 GeV
  - Overlap removal with electrons and muons
- B-tagged jet
  - Identified using the MV2 b-tagging algorithm, with an efficiency of 85%

Object reconstruction

- MET: missing transverse momentum
  - E_T^{miss}: calorimeter-based

    Negative vectorial sum of the transverse momenta of all calibrated selected objects

    Tracks compatible with the primary vertex but not matched to the objects also included
  - p_T^{miss}: track-based

    negative sum of the momenta of ID tracks, satisfying:
    - $d_0 < 1.5$mm, $d_0/\sigma(d_0) < 3$
    - $|\eta| < 2.5$, $p_T > 500$ MeV

    Calorimeter electron p_T used instead of track p_T

Event selection

Preselection cuts: $e^{\pm}\mu^{\mp}$, $\mu^{\pm}e^{\mp}$, $p_T^{\text{lead}} > 25$ GeV, $p_T^{\text{sublead}} > 15$ GeV, third lepton veto							
	Signal region			WW control region		Top-quark control region	
	$N_{\text{jet}} = 0$	$N_{\text{jet}} = 1$	$N_{\text{jet}} \geq 2$	$N_{\text{jet}} = 0$	$N_{\text{jet}} = 1$	$N_{\text{jet}} = 1$	$N_{\text{jet}} \geq 2$
$\|\Delta\eta_{\ell\ell}\|$	< 1.8	< 1.8	< 1.8	> 1.8	> 1.8		
$N_{b\text{-jet}}$		$= 0$	$= 0$		$= 0$	$= 1$	$= 1$
p_T^{lead}	> 120 GeV	> 120 GeV	> 120 GeV	> 30 GeV	> 30 GeV		
p_T^{sublead}		> 40 GeV	> 40 GeV	> 30 GeV	> 30 GeV		
p_T^{miss}	> 40 GeV	> 40 GeV		> 20 GeV	> 20 GeV		
$m_{\ell\ell}$	> 100 GeV	> 100 GeV	> 150 GeV	> 100 GeV	> 100 GeV	> 100 GeV	> 150 GeV
m_{jj}			> 650 GeV				
$\|\Delta y_{jj}\|$			> 4.25				

- Re-optimized with Run 1 samples
  1. Select the most discriminating variables from the BDT training

     Remove duplicated variables that highly correlated
  2. Choose cut values for each variable by maximizing the signal significance
- Optimization internal note: https://cds.cern.ch/record/2128947

  L. Ma, X. Zhang, Z. Zhang and Y. Zhao, A simple and general strategy for optimising event selection of a search or precision measurement analysis
- Subleading p_T and p_T^{miss} cuts in WW CR mainly used to suppress W+jets background

Background estimation

- WW

  Normalized from background-only fit in SRs and CRs, except that

  WW in SR 2J predicted from simulation

  * The fit performed simultaneously in SRs(0J, 1J and 2J), WW CRs(0J, 1J) and Top CRs(1J, 2J)

- Top

  Normalization together with WW, except that

  Top in SR 0J estimated using "JVSP" method (http://arxiv.org/abs/1101.1383)

- Wjets

  Data-driven method

- Zjets, Diboson

  Small, predicted from simulation

- H125

  Small, off-shell component included, interference with WW considered

➢ Normalization factor calculation from CRs (WW CR 0J for example):

$$NF = \frac{N_{Data}^{WW0JCR} - N_{OtherBkg}^{WW0JCR}}{N_{WW}^{WW0JCR}}$$

Systematics

- Luminosity uncertainty: 5%
- Main experimental uncertainties (relative number in %):

	Top-quark			WW	
	$N_{\text{jet}} = 0$	$N_{\text{jet}} = 1$	$N_{\text{jet}} \geq 2$	$N_{\text{jet}} = 0$	$N_{\text{jet}} = 1$
Small jets	11	2.2	14.2	2	9.2
Muon reco.	0.5	0.4	0.6	0.9	0.7
Electron reco.	1.2	0.8	0.8	1.3	1.3
b-tagging, eff.	2.4	9.9	3.8	–	< 0.1
b-tagging, c-quarks	< 0.1	0.2	0.3	–	< 0.1
b-tagging, light quarks	0.1	1.2	0.9	–	< 0.1

- Theoretical uncertainties (relative number in %)
  - on signal samples:

Error source	$N_{\text{jet}} = 0$	$N_{\text{jet}} = 1$	$N_{\text{jet}} \geq 2$
PDF	2.0	1.0	6.0
PS	4.5	3.0	28
Scale	0.5	0.3	3.0

    - Also, the uncertainties from event migration among jet bins due to variations of QCD renormalisation and factorisation were considered
    - For example, for m_H = 600 GeV, it's 38%, 48% and 64% for N_{jets} = 0, 1 and ≥ 2 categories

Systematics

- Theoretical uncertainties
  - on WW background

Error source	$N_{\text{jet}} = 0$	$N_{\text{jet}} = 1$
ME+PS	$+3.7 \pm 2.8$	$+12.9 \pm 3.0$
Renormalisation scale (0.5/2)	(-4.0 ± 2.5) / $(+1.2 \pm 2.3)$	(-3.2 ± 2.7) / $(+2.6 \pm 2.5)$
Factorisation scale (0.5/2)	(-1.4 ± 2.4) / $(+1.7 \pm 2.5)$	(-0.3 ± 2.5) / $(+3.3 \pm 2.8)$
Qsf scale (0.5/2)	(-2.6 ± 2.4) / $(+1.3 \pm 2.5)$	(-3.2 ± 2.5) / $(+2.4 \pm 2.6)$
CKKW matching	(-4.6 ± 3.1) / $(+3.3 \pm 2.4)$	$(+0.7 \pm 3.2)$ / (-0.1 ± 2.5)
PDF (down/up)	$-3.1/+2.6$	$-1.7/+1.8$

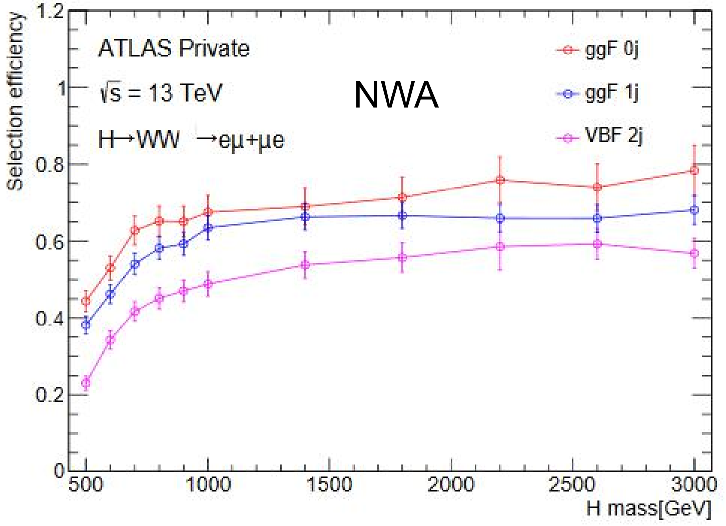
  - on Top background

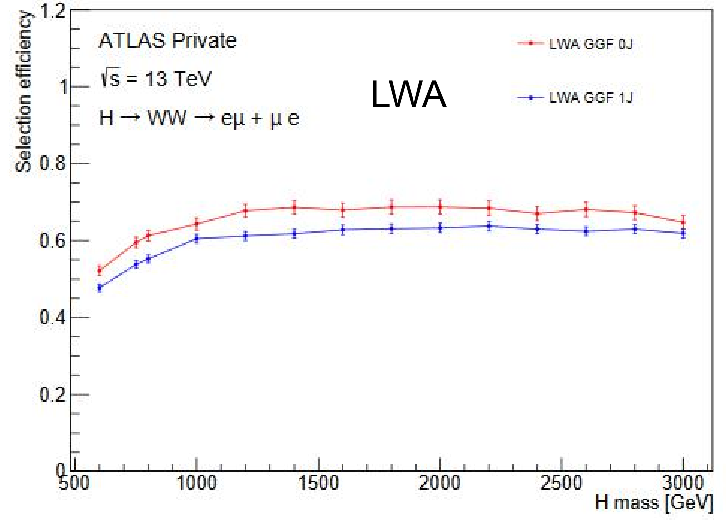
Error source	$N_{\text{jet}} = 0$	$N_{\text{jet}} = 1$	$N_{\text{jet}} \geq 2$
ME	-2.4 ± 3.8	$+2.8 \pm 2.4$	$+42 \pm 14$
PS	-1.0 ± 2.9	$+3.7 \pm 1.8$	$+29 \pm 10$
Radiation (radHi/radLo)	$(+3.3 \pm 2.2)$ / $(+0.1 \pm 2.2)$	(-5.7 ± 1.3) / $(+2.2 \pm 1.3)$	$(+16.4 \pm 7.2)$ / $(+8.5 \pm 6.9)$
$Wt - t\bar{t}$ interference	-1.8 ± 1.5	-1.7 ± 0.9	$+0.3 \pm 4.5$
Relative variation of $\sigma_{st}(\pm 20\%)$	(-1.3 ± 0.1) / $(+1.3 \pm 0.1)$	(-0.5 ± 0.1) / $(+0.5 \pm 0.1)$	$(+1.3 \pm 0.2$ / (-1.3 ± 0.2)
PDF (down/up)	$-0.4/+2.9$	$-1.8/+2.5$	$-2.9/+3.3$

- Total systematic uncertainty on data-driven Wjets background is ~ 60%

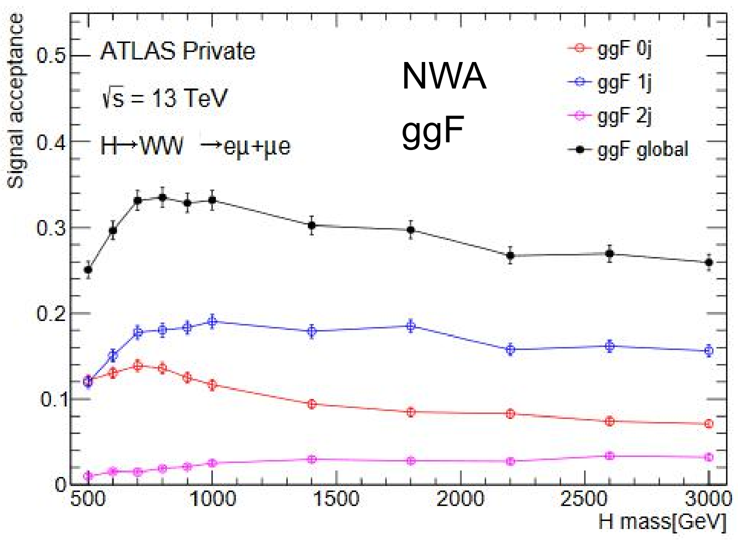
Signal acceptance*efficiency

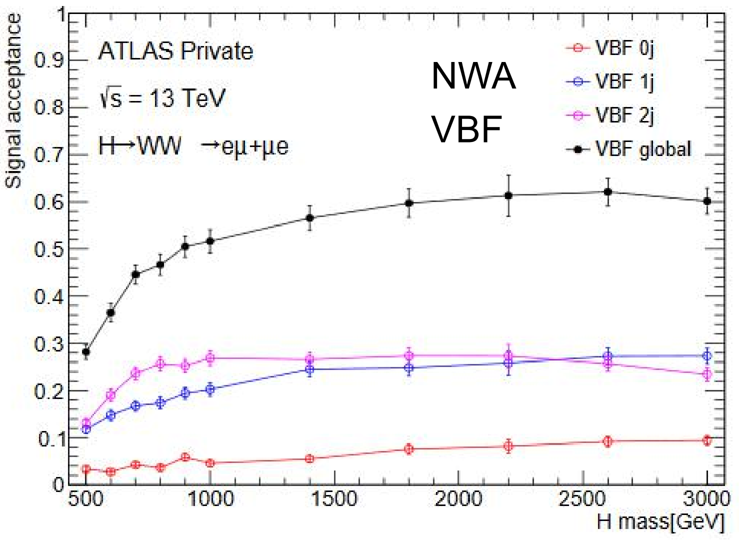
- Selection efficiency (not including pre-selection cuts)





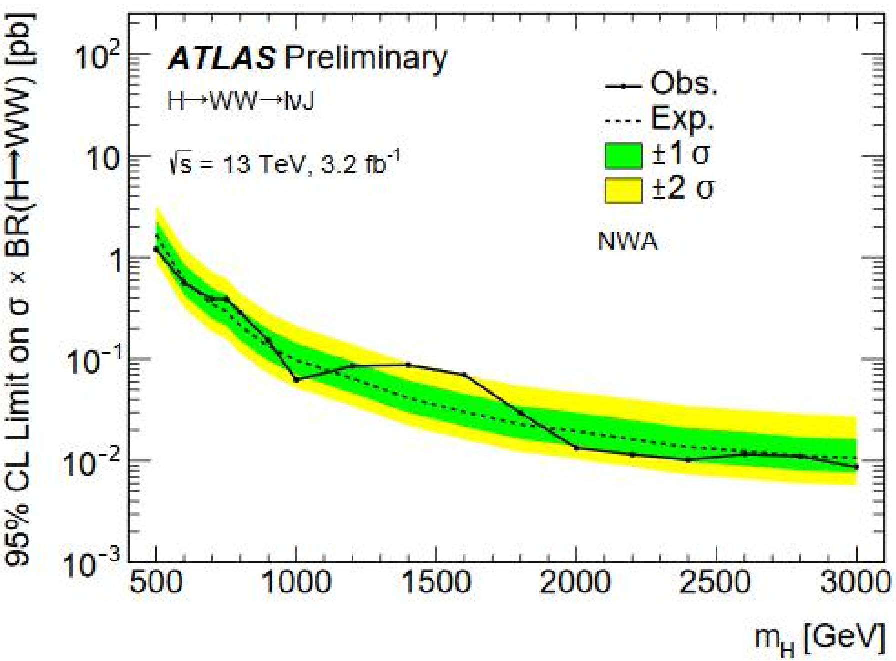
- Acceptane*efficiency (namely the overall efficiency after all selections in SR)



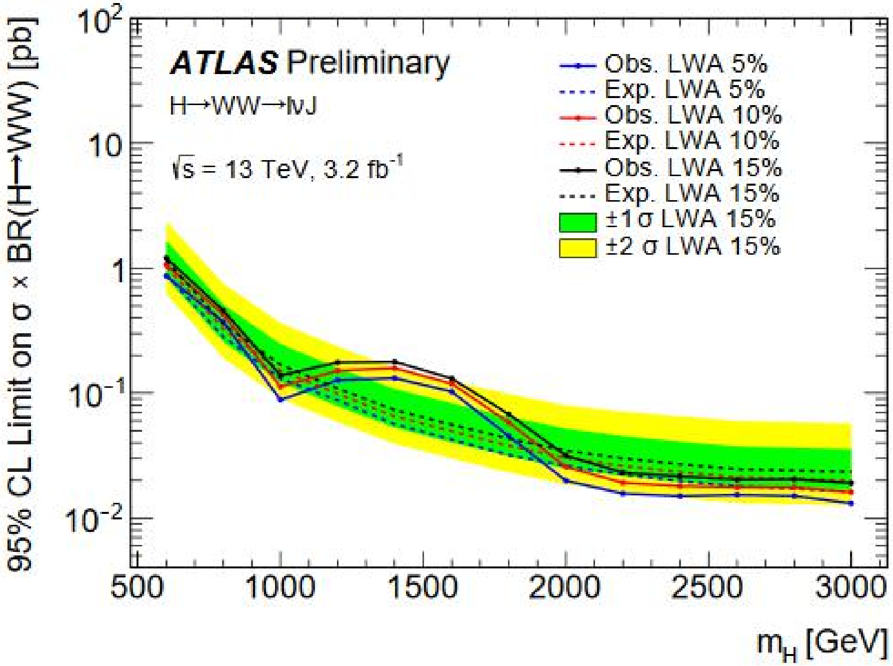


Results from the H→WW→lvqq team/analysis

- 95% CL upper limits
  - only boosted jets considered



(a) NWA



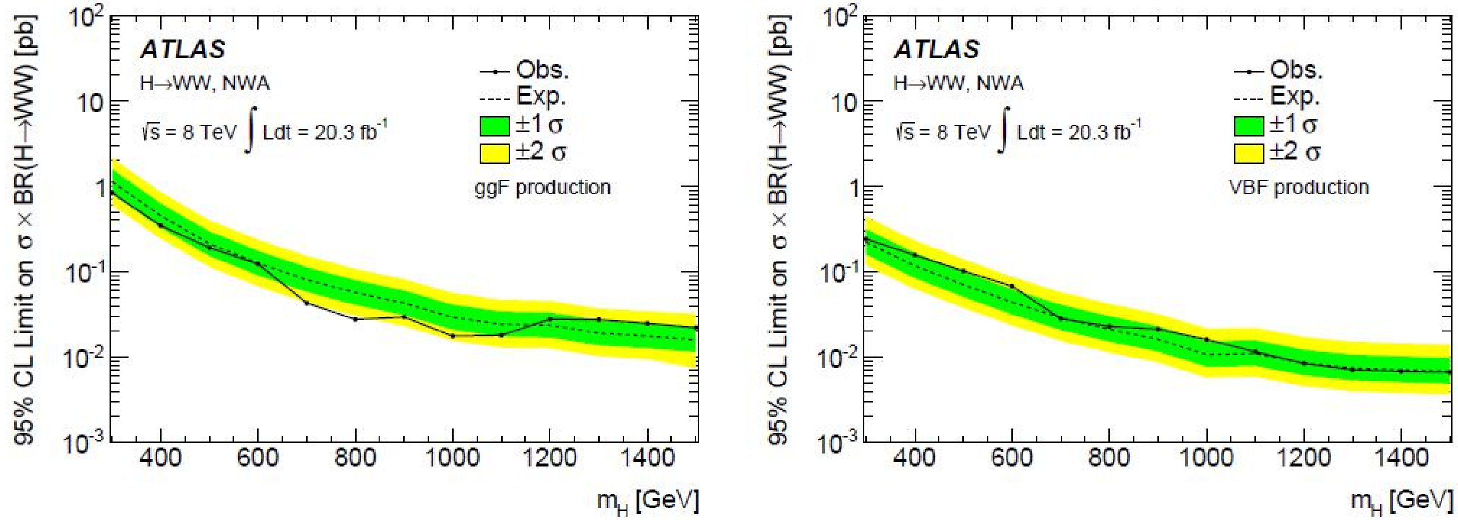
(b) LWA

Results: combination of lvlv and lvqq analyses

- H→WW→lvlv and H→WW→lvqq combined upper limits on $\sigma_H \times BR(H \rightarrow WW)$

Run 1

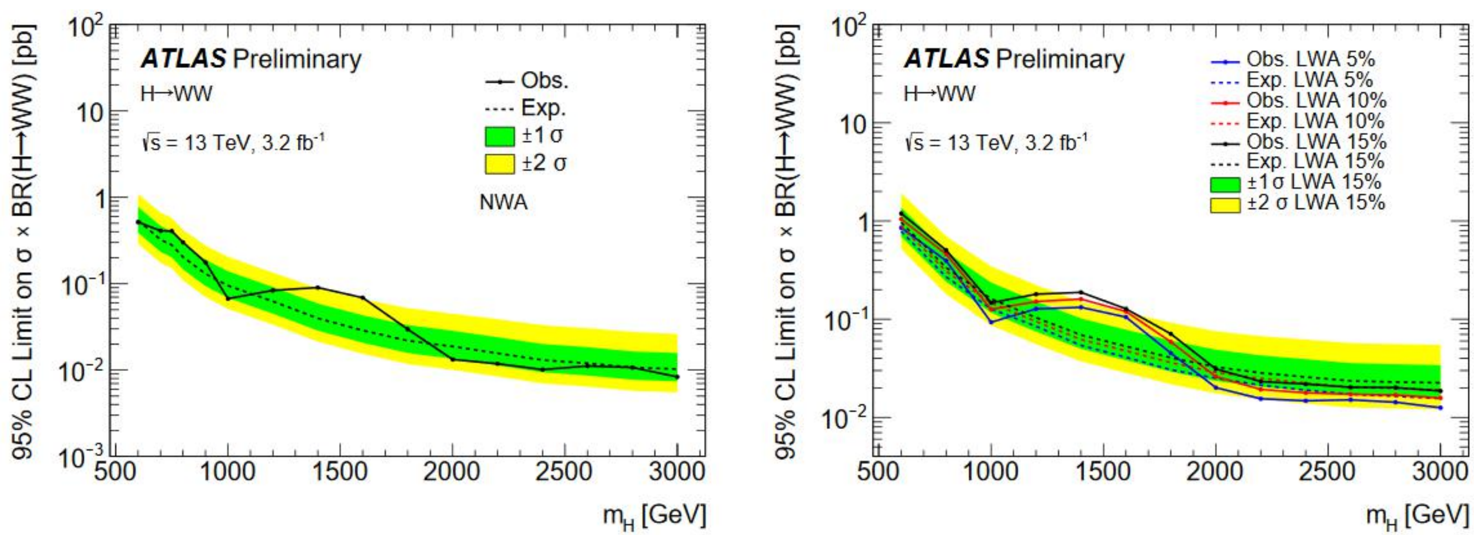
m_H: 300-1500 GeV



Run 2

ggF only

m_H: 600-3000 GeV



(a) NWA (b) LWA