



Search for associated production of the Higgs boson in the $H \rightarrow WW$ channel with a fully leptonic final state with the ATLAS detector

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Overview

- The Standard Model Higgs boson
 - Production Cross Section (at LHC)
 - Higgs Branching Ratio
- The WH associated production
 - WH(WW) → lνlν analysis
- The ZH associated production
 - ZH(WW) → llνν analysis
- Combination with other H(WW) production mechanisms

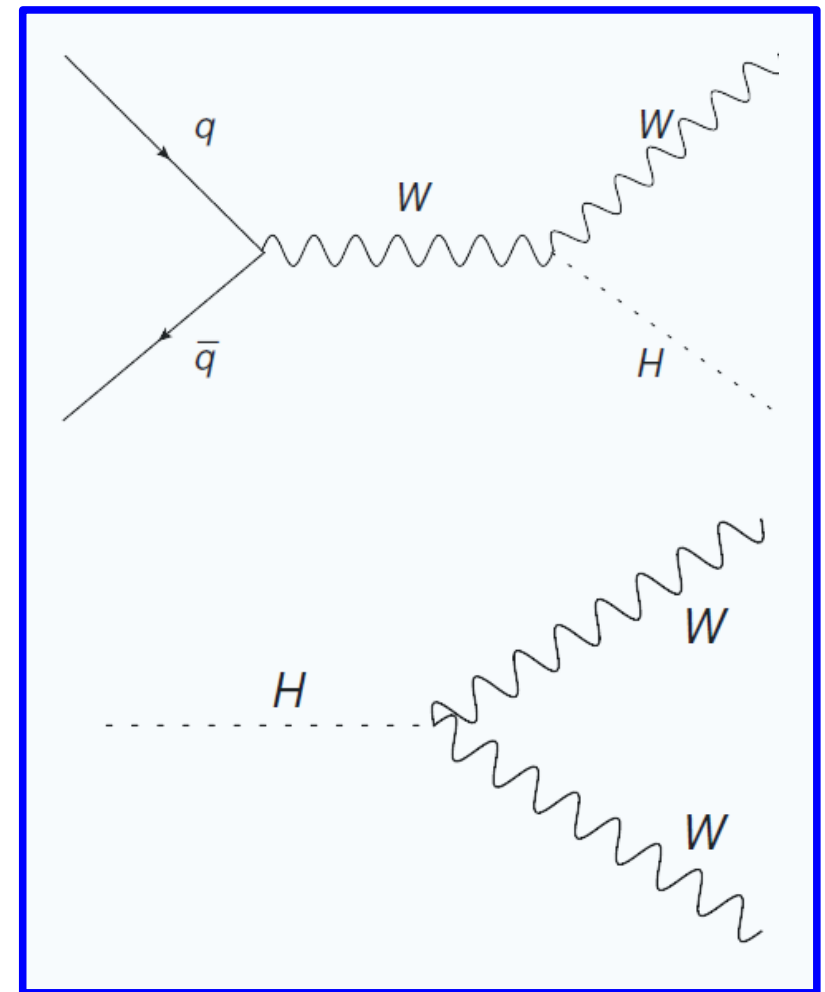
Introduction

Why the associated production?

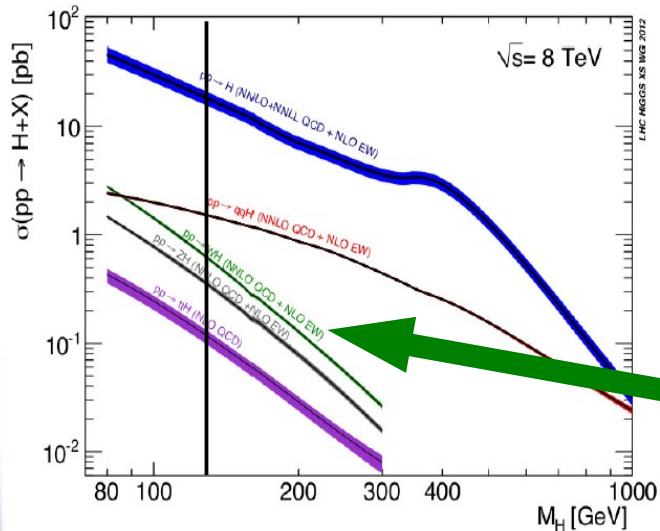
After the discovery of the Higgs boson particle by the ATLAS and CMS experiments (4th July 2012) it became interesting to study its coupling to other SM particles to test the validity of the SM

Why this analysis?

Particularly sensitive to the H-W couplings when considering the WH and sensitive to H-W and H-Z coupling when considering the ZH channel



The Standard Model Higgs boson



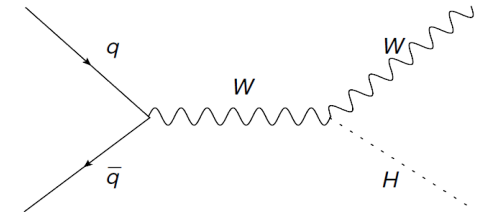
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Higgs boson production Cross Section (pb) at LHC $m_H = 125$ GeV

	ggf	vbf	WH	ZH	$t\bar{t}H$
7 TeV	15.13	1.222	0.5785	0.3351	0.0863
8 TeV	19.27	1.578	0.7046	0.4153	0.1293

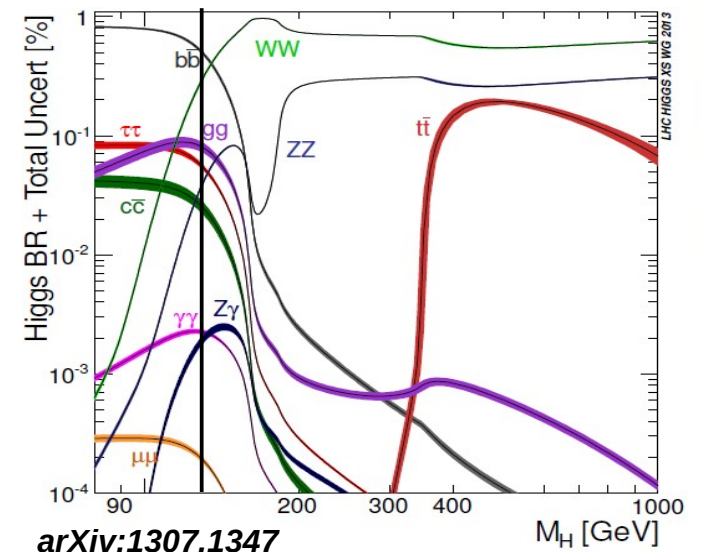
Associated production



arXiv:1307.1347

Branching Ratio (BR) at $m_H = 125$ GeV

$H \rightarrow b\bar{b}$	$H \rightarrow WW^{(*)}$	$H \rightarrow \tau\tau$	$H \rightarrow ZZ^{(*)}$	$H \rightarrow \gamma\gamma$
0.577	0.215	0.0632	0.0264	0.00228



arXiv:1307.1347

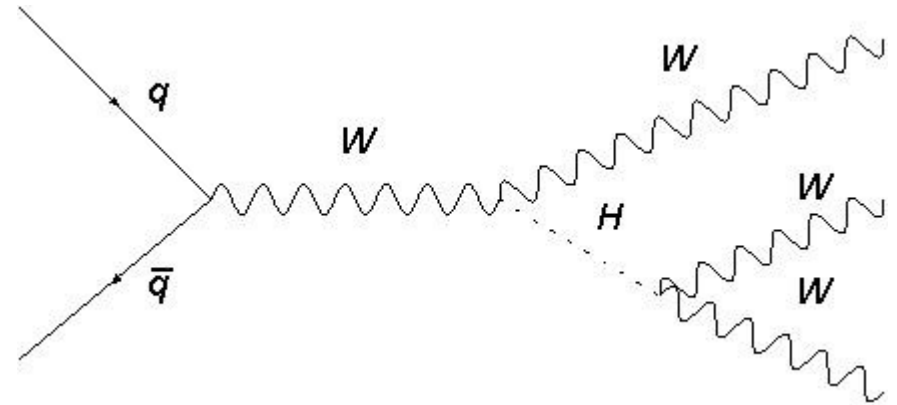
The Analyses

- 3 lepton analysis
 - Aiming at $WH(WW) \rightarrow l\nu l\nu l\nu$
- 4 lepton analysis
 - Aiming at $ZH(WW) \rightarrow ll\nu l\nu$

3-lepton analysis

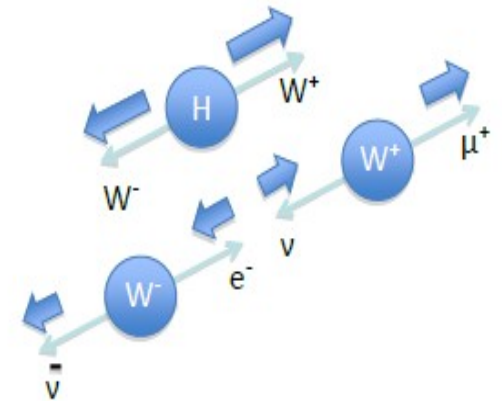
The analysis presented by the ATLAS collaboration (ATLAS-CONF-2013-075) is focused on the WH associated production with a Standard Model Higgs boson decay in WW and a fully leptonic final state.

- Only 3 leptons
- Sum Charges $|Q| = 1$
- Low hadronic activity (jets)
- No B-tagged jet
- Presence of real missing energy



Due to the spin 0 nature of the SM Higgs Boson there is an additional signature typical of the $H \rightarrow WW$ events:

Small opening angle between the leptons coming from the Higgs boson decay
(defined as lep_0 and lep_1)



3-lepton analysis

The main sources of background for this analysis are all the processes with 3 leptons and missing energy in the final state

VV

W(Z/ γ^*): a Same Flavor Opposite Sign lepton pair is always present

→ analysis divided in two samples:

- with SFOS ($\frac{3}{4}$ of the signal, all the W(Z/ γ^*))

- without SFOS ($\frac{1}{4}$ of the signal, W(Z/ γ^*) suppressed)

ZZ*, WW*: entering in presence of lepton inefficiencies or fake leptons

Fake leptons

mainly $t\bar{t}$, Wt and Z+jets

→ present in both categories

→ reducible through lepton isolation

VVV

mainly WWW

→ irreducible background

→ cross-section comparable to the signal

3-lepton analysis

Analysis selections

- *Low hadronic activity*
- *Real Missing energy*
- *Dilepton invariant mass*
- *Opening angle (between the leptons coming from the Higgs)*
- *Overlap with other production mechanism involving the $H \rightarrow WW$ decay*

Signal Selections ATLAS-CONF-2013-075		
Cut	Z-enriched	Z-depleted
Jet multiplicity	SFOS $N_{\text{jet}} \leq 1$	w/o SFOS
b -veto	$N_{b\text{-tag}} = 0$	
$E_{T,\text{rel}}^{\text{miss}}$ cut	$E_{T,\text{rel}}^{\text{miss}} > 40$ GeV	$E_{T,\text{rel}}^{\text{miss}} > 25$ GeV
Dilepton mass cuts	$ m_{\ell\ell} - m_Z > 25$ GeV and $m_{\ell\ell} > 12$ GeV	$m_{\ell\ell} > 12$ GeV
Angular cut	$\Delta R_{\ell_0\ell_1} < 2.0$	
Overlap removal	remove overlap with $H \rightarrow WW$ analysis [6]	

Four control regions are defined to normalize the background estimates from MC to the data

Control Region	Selections	ATLAS-CONF-2013-075
$W(Z/\gamma^*)$ CR	at most one jet with $p_T > 25$ GeV;	$E_{T,\text{rel}}^{\text{miss}} > 25$ GeV at least one SFOS lepton pair with $ m_{\ell\ell} - m_Z < 25$ GeV
$ZZ^{(*)}$ CR	no b -tagged jets with $p_T > 25$ GeV;	$E_{T,\text{rel}}^{\text{miss}} < 40$ GeV $ m_{\ell\ell\ell} - m_Z < 15$ GeV
Z+jets CR	$m_{\ell\ell,\text{min}} > 12$ GeV; $\Delta R_{\ell_0\ell_1} < 2.0$	$E_{T,\text{rel}}^{\text{miss}} < 40$ GeV at least one SFOS lepton pair with $ m_{\ell\ell} - m_Z < 25$ GeV
Top CR	at least one b -tagged jet with $p_T > 25$ GeV $m_{\ell\ell,\text{min}} > 12$ GeV; $\Delta R_{\ell_0\ell_1} < 2.0$	$E_{T,\text{rel}}^{\text{miss}} > 40$ GeV all SFOS lepton pairs with $ m_{\ell\ell} - m_Z > 25$ GeV

3-lepton analysis

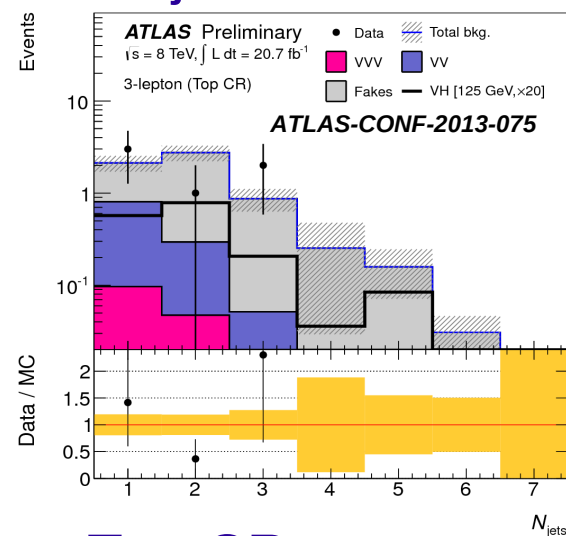
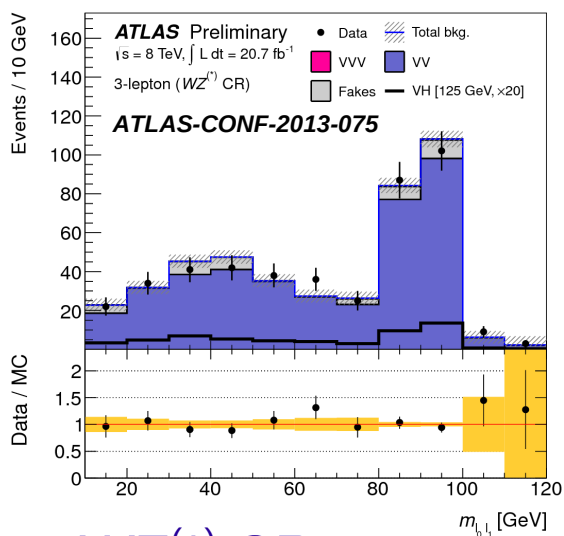
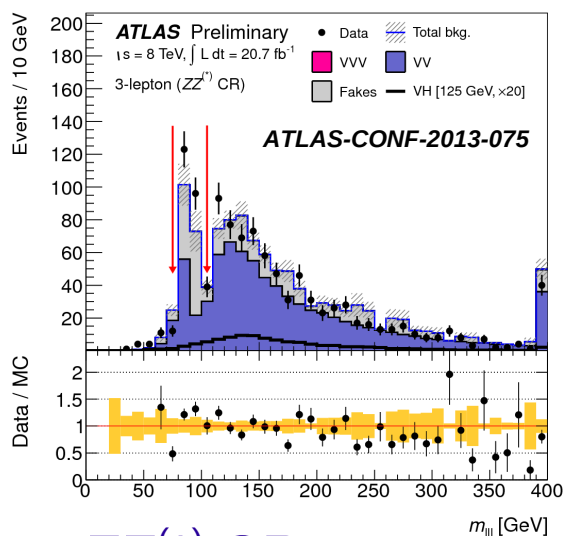
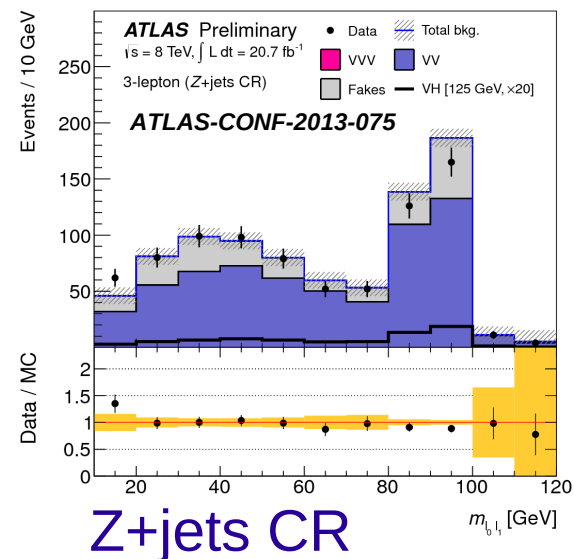
Normalization factor values computed in the 2012 analysis

$WZ^{(*)}$	$0.92 \pm 0.03 \pm 0.02$
$ZZ^{(*)}$	$2.33 \pm 0.30 \pm 0.10$
Z+jets (electrons)	$0.72^{+0.1}_{-0.03} \pm 0.04$
Z+jets (muons)	$0.76 \pm 0.80 \pm 0.04$
Top	$1.15 \pm 0.70 \pm 0.03$

Systematic uncertainty

Statistical uncertainty

ATLAS-CONF-2013-075



3-lepton analysis result (2012 + 2011)

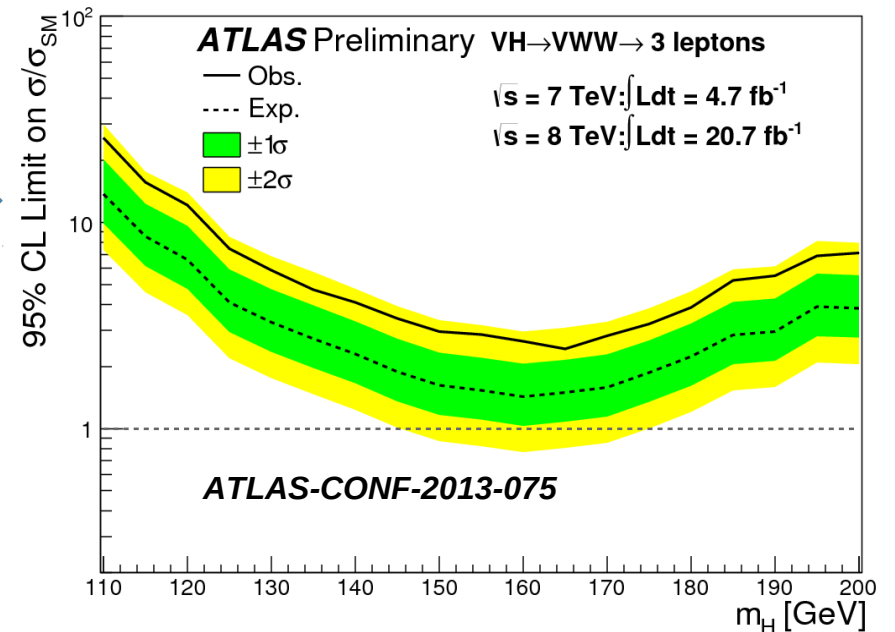
ATLAS-CONF-2013-075

2012	VVV	VV	Fakes	VH(WW)	Data
2SFOS	0.63 ± 0.06	8.7 ± 0.5	4 ± 4	0.42 ± 0.03	8
1SFOS	1.56 ± 0.11	10.1 ± 0.6	0.5 ± 0.2	1.04 ± 0.04	16
0SFOS	1.45 ± 0.09	0.68 ± 0.12	0.58 ± 0.35	0.88 ± 0.04	9

ATLAS-CONF-2012-078

2011	WZ	WW	ZZ	Top	VH(WW)	Data
SFOS	3.2 ± 0.8	0.09 ± 0.06	0.17 ± 0.07	0.28 ± 0.12	0.39 ± 0.06	3
0SFOS	0.21 ± 0.07	0.00 ± 0.05	0.03 ± 0.03	0.01 ± 0.10	0.22 ± 0.04	0

- CLs Limit @ 125GeV: 7.5 obs. - 4.1 exp.
- P_0 @ 125 GeV: 1.6σ
- P_1 @ 125 GeV: 1.1σ



4-lepton analysis

The analysis presented by the ATLAS collaboration (ATLAS-CONF-2013-075) is focused on the ZH associated production with a Standard Model Higgs boson decay in WW and a totally leptonic final state.

• Topology

- Only 4 leptons
- Sum Charge = 0
- Large missing ET
- A pair of lepton with $m_{ll} \approx m_Z$
- Low jet activities

• Background

- VV (mainly ZZ^(*))
- VVV
- Fakes

• Leptons Definition

- The leptons are divided in lep₀-lep₁ from Higgs candidate and lep₂-lep₃ ($m_{ll} \approx m_Z$)
- $P_{T0} > P_{T1}$ and $P_{T2} > P_{T3}$

4-lepton analysis

Analysis selections

- *Real Missing energy*
- *Leptons p_T*
- *Low hadronic activity*
- *Dilepton invariant mass*
- *Angular selection*
- *Overlap with other production mechanism involving the $H \rightarrow WW$ decay*

Signal Selections ATLAS-CONF-2013-075	
Cut	
E_T^{miss} cut	$E_T^{\text{miss}} > 30 \text{ GeV}$
p_T^ℓ cuts	highest p_T lepton: $p_T > 25 \text{ GeV}$ second highest p_T lepton: $p_T > 20 \text{ GeV}$ third highest p_T lepton: $p_T > 15 \text{ GeV}$ fourth highest p_T lepton: $p_T > 10 \text{ GeV}$
Jet multiplicity	$N_{\text{jet}} \leq 1$
b -veto	$N_{b\text{-tag}} = 0$
Mass cuts	$ m_{\ell_2\ell_3} - m_Z < 10 \text{ GeV}$ $10 \text{ GeV} < m_{\ell_0\ell_1} < 65 \text{ GeV}$
Angular cut	$\Delta\phi_{01}^{\text{boost}} < 2.5$
Channel separation	2SFOS
$p_{T4\ell}$ cut	$p_{T4\ell} > 30 \text{ GeV}$
$m_{4\ell}$ cut	$m_{4\ell} > 130 \text{ GeV}$
Overlap removal [6]	remove overlap with $H \rightarrow WW$ analysis

One control region to normalize the main MC background sample ($ZZ^{(*)}$) to the data

The resulting normalization factor is

$$ZZ \longrightarrow 0.908^{+0.095}_{-0.088}$$

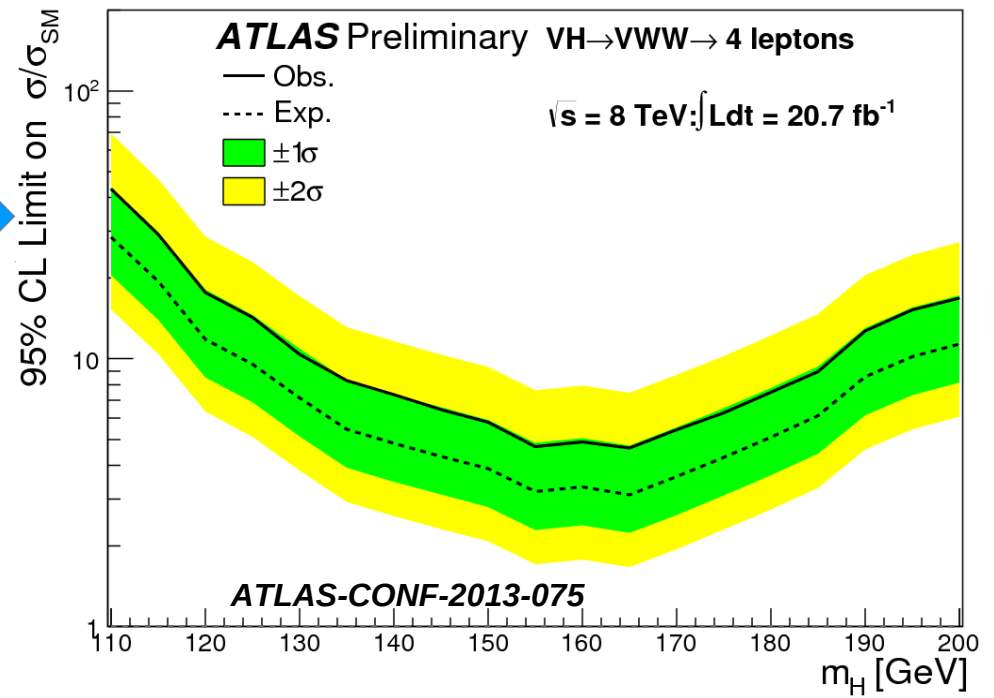
	Selection
	2 SFOS pairs of isolated leptons
	highest p_T lepton: $p_T > 25 \text{ GeV}$ second highest p_T lepton: $p_T > 20 \text{ GeV}$ third highest p_T lepton: $p_T > 15 \text{ GeV}$ fourth highest p_T lepton: $p_T > 10 \text{ GeV}$ at most one jet with $p_{T,\text{jet}} > 25 \text{ GeV}$ no b -tagged jets with $p_T > 25 \text{ GeV}$ $ m_{\ell_2\ell_3} - m_Z < 10 \text{ GeV}$
ZZ CR	$m_{\ell_0\ell_1} > 65 \text{ GeV}$
	overlap removal with dilepton analysis

4-lepton analysis result (2012)

ATLAS-CONF-2013-075

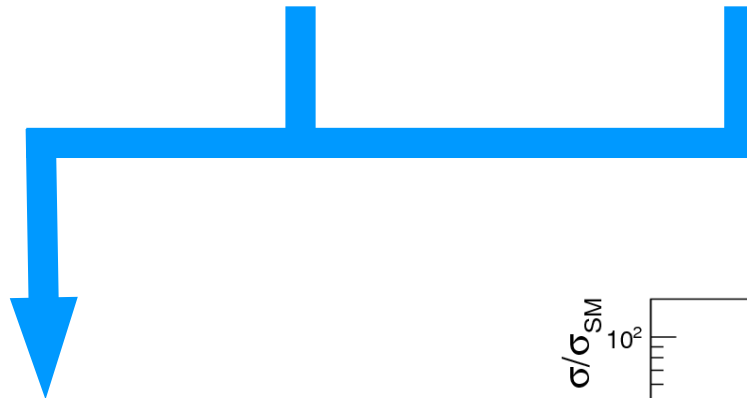
2012	ZZ	VVV	Fakes	VH(WW)	Data
2SFOS	0.70 ± 0.07	0.10 ± 0.01	0.04 ± 0.02	0.17 ± 0.01	0
1SFOS	0.23 ± 0.07	0.08 ± 0.01	0.00 ± 0.01	0.18 ± 0.01	2

- CLs Limit @ 125 GeV: 14.3 obs. - 9.6 exp.
- P_0 @ 125 GeV: 1.5σ
- P_1 @ 125 GeV: 1.0σ

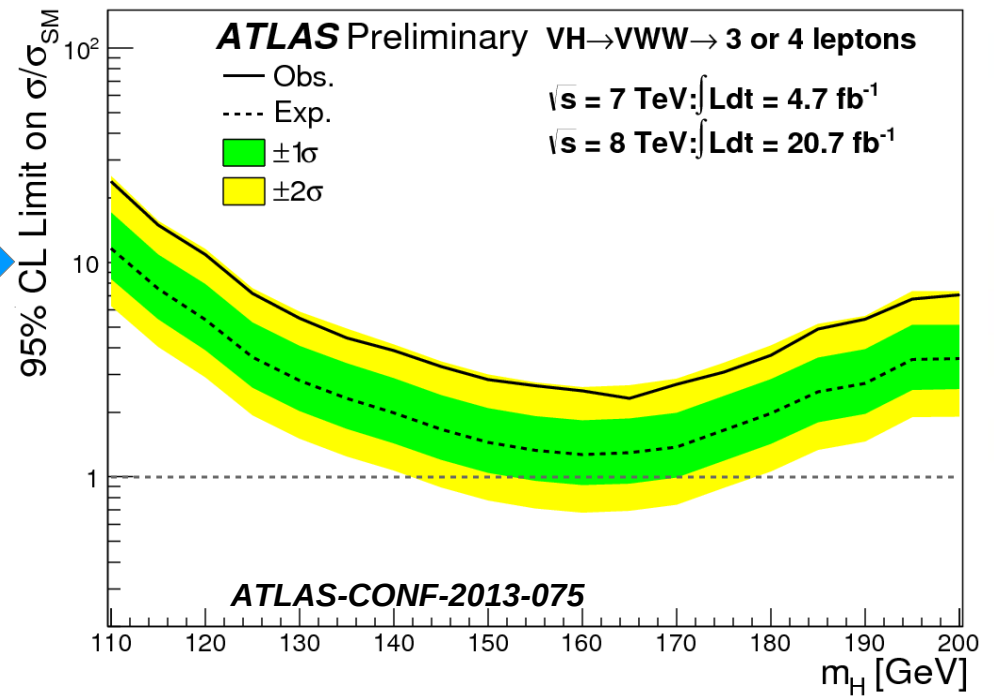


VH(WW) result

Combining the 3 lepton and 4 lepton analyses



- CLs Limit @ 125 GeV:
7.2 obs. - 3.6 exp.
- P_0 @ 125 GeV: 2.0σ
- P_1 @ 125 GeV: 1.4σ



Conclusion

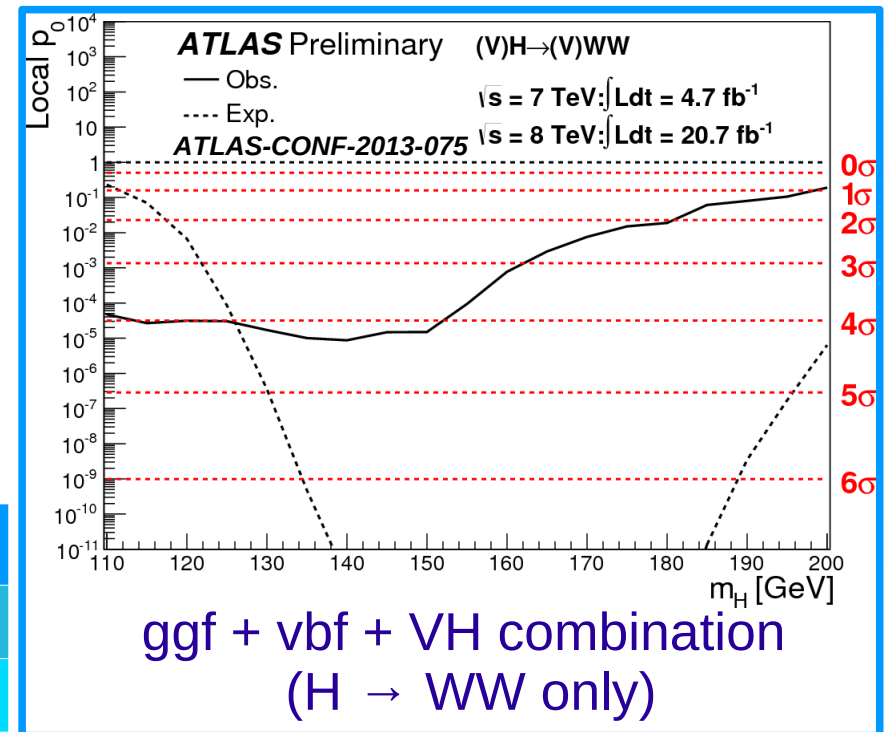
Main goal of Higgs analyses: study the properties of the new boson

Associate production: helps in disentangling the Higgs to bosons couplings from the Higgs to fermions

The results presented today:

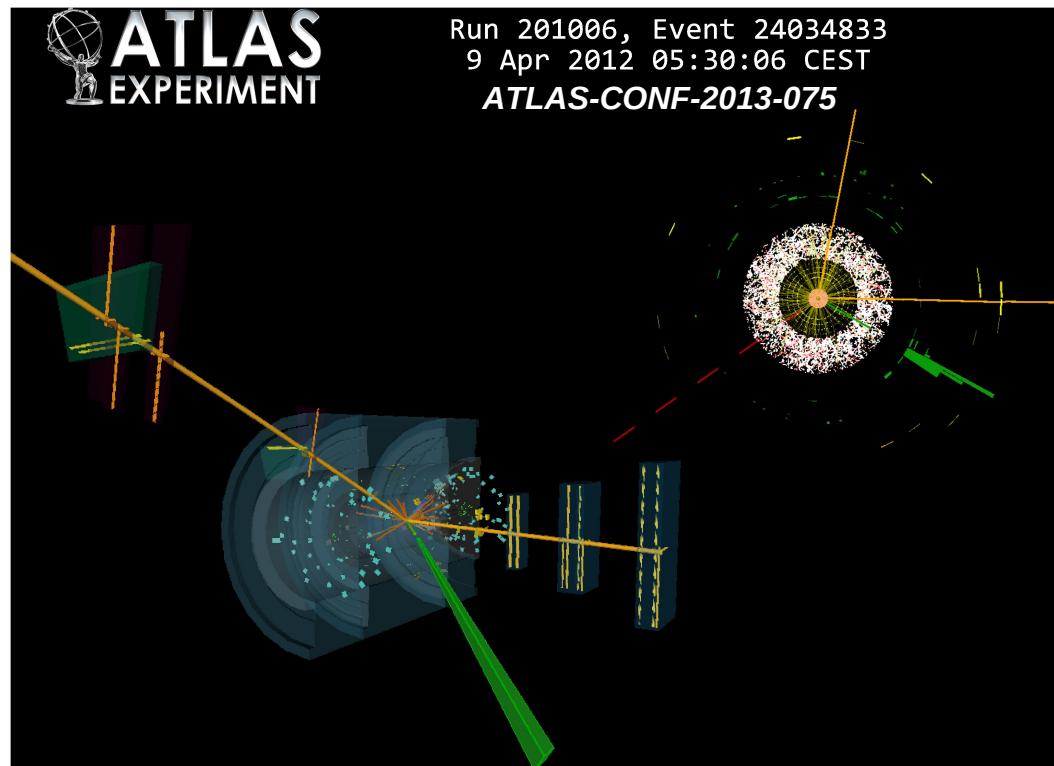
- sets an upper limit on the VH couplings in agreement with SM expectations
- contributes to the overall significance of the Higgs boson observation in the WW decay channel

p_0 at $m_H = 125$ GeV (σ)	VH	ggf+vbf	Combined
Expected	0.7	3.7	3.8
Observed	2.0	3.8	4.0



For the future (Run II): with higher statistics ATLAS will become sensitive to the VH production and a direct and precise measurement of the VH couplings will be achievable with this production mechanism

Thanks for the attention



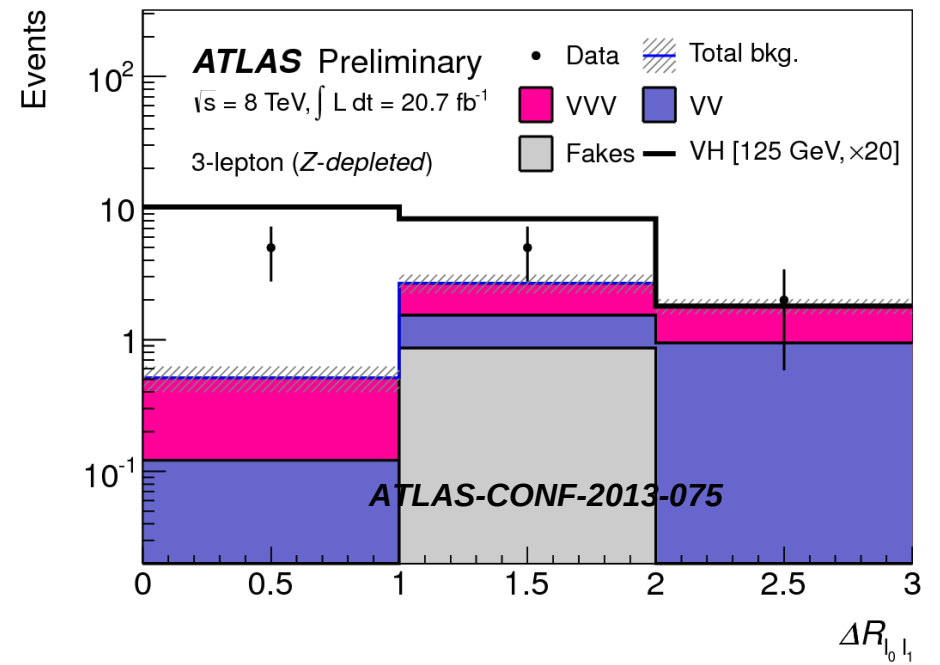
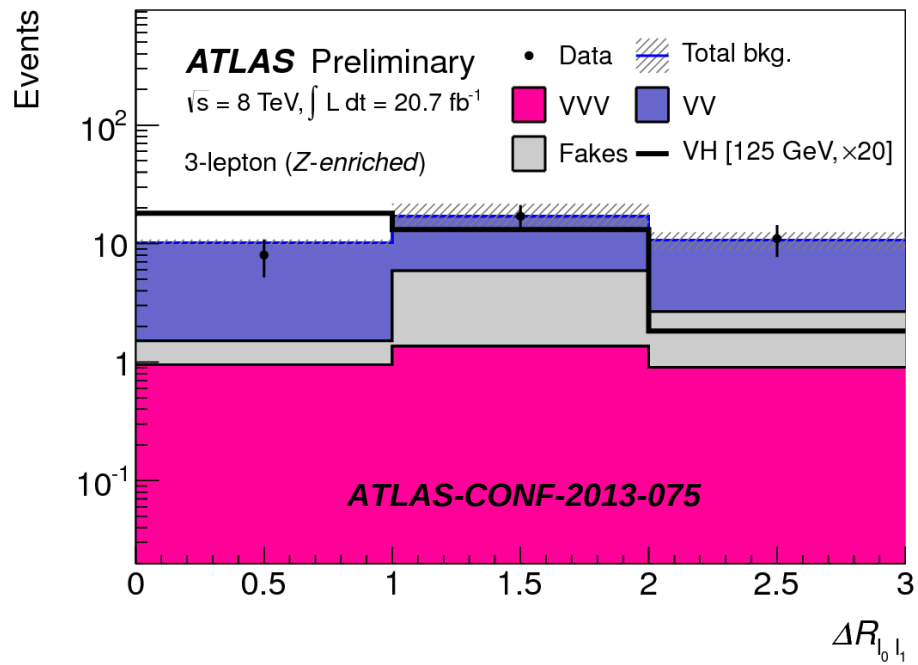
BACK UP

3 lepton analysis (2012)

	VVV	VV	Fakes	Total Bkg.	VH(125)	Data
3 leptons	19.5±0.5	2410±50	930±100	3370±150	18.53±0.25	3717
<i>Z-enriched (eee + μμμ)</i>	5.89±0.18	1228±23	380±40	1620±50	7.31±0.17	1711
Jet multiplicity and <i>b</i> -veto	4.79±0.19	1064±24	273±33	1350±50	4.85±0.13	1321
$E_{T,rel}^{miss}$ cut	2.51±0.13	241±6	12±7	256±12	1.72±0.07	252
Dilepton mass cuts	0.86±0.07	12.2±0.6	5±5	18±5	0.48±0.03	12
Angular cut	0.64±0.06	9.0±0.5	4±4	14±4	0.45±0.03	9
Overlap removal	0.63±0.06	8.7±0.5	4±4	14±4	0.42±0.03	8
<i>Z-enriched (eeμ + μμe)</i>	9.54±0.29	1180±29	530±90	1730±120	9.25±0.18	1968
Jet multiplicity and <i>b</i> -veto	7.97±0.29	1008±29	420±90	1440±120	6.56±0.14	1490
$E_{T,rel}^{miss}$ cut	4.24±0.19	219±7	12±6	235±12	2.37±0.08	247
Dilepton mass cuts	2.35±0.13	15.6±0.8	2.3±1.8	20.3±2.3	1.17±0.05	24
Angular cut	1.67±0.11	10.8±0.6	0.65±0.22	13.2±0.8	1.11±0.04	16
Overlap removal	1.56±0.11	10.1±0.6	0.50±0.20	12.2±0.7	1.04±0.04	16
<i>Z-depleted</i>	4.10±0.16	6.0±0.4	20±4	30±4	1.98±0.06	38
Jet multiplicity and <i>b</i> -veto	3.61±0.16	4.79±0.33	7±4	15±4	1.66±0.05	16
$E_{T,rel}^{miss}$ cut	2.42±0.12	1.82±0.20	0.8±0.4	5.0±0.6	1.05±0.04	12
Dilepton mass cut	2.40±0.12	1.81±0.20	0.8±0.4	5.0±0.6	1.01±0.04	12
Angular cut	1.54±0.09	0.86±0.14	0.8±0.4	3.2±0.5	0.92±0.04	10
Overlap removal	1.45±0.09	0.68±0.12	0.58±0.35	2.7±0.5	0.88±0.04	9

ATLAS-CONF-2012-078

3-lepton analysis (2012)



3 lepton analysis (2012)

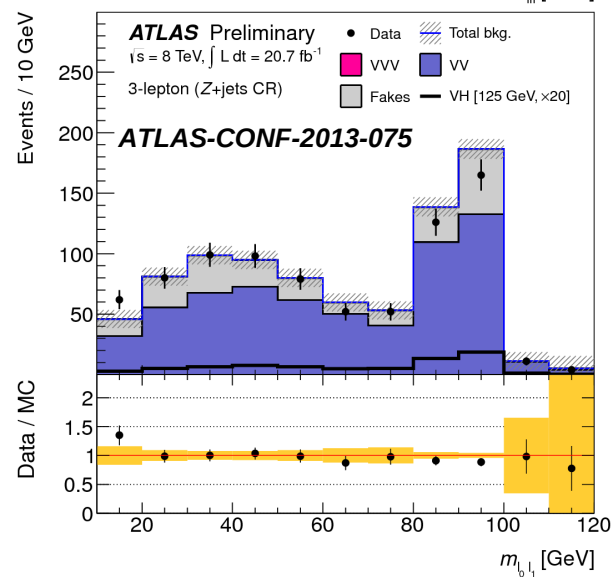
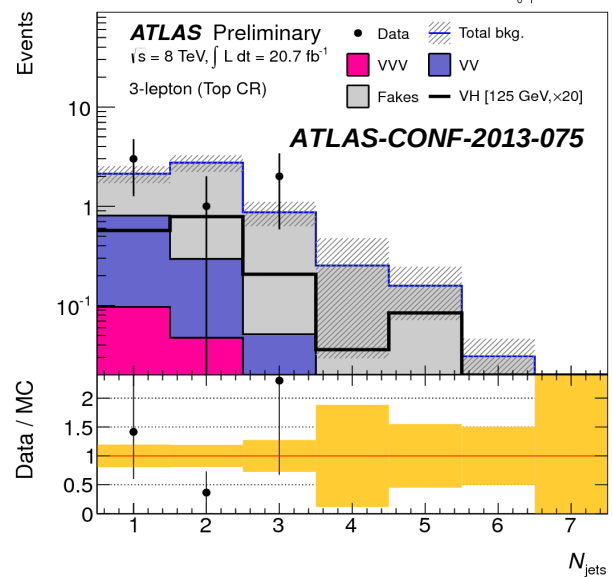
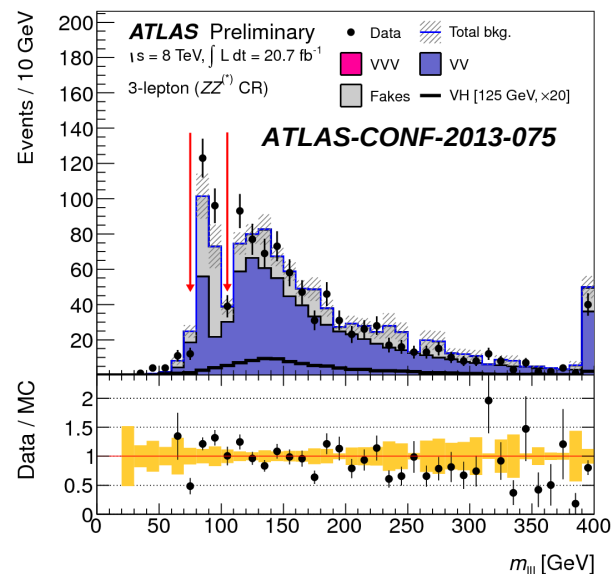
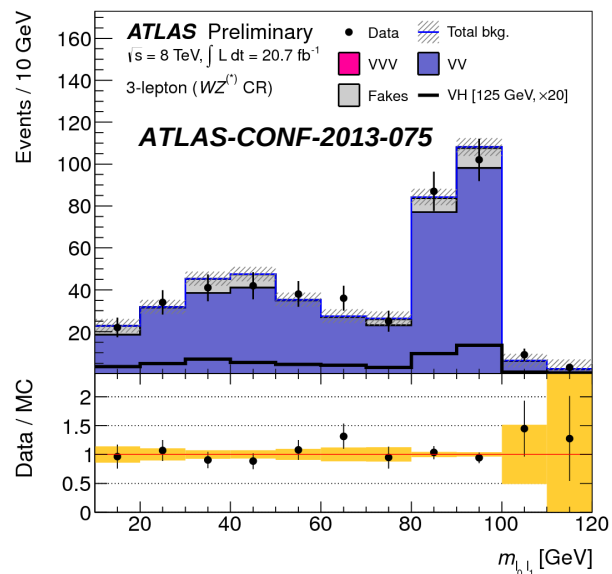
Control Region	Selections	
$W(Z/\gamma^*)$ CR	at most one jet with $p_T > 25$ GeV;	$E_{T,rel}^{miss} > 25$ GeV at least one SFOS lepton pair with $ m_{\ell\ell} - m_Z < 25$ GeV
$ZZ^{(*)}$ CR	no b -tagged jets with $p_T > 25$ GeV;	$E_{T,rel}^{miss} < 40$ GeV $ m_{\ell\ell\ell} - m_Z < 15$ GeV
Z+jets CR	$m_{\ell\ell,min} > 12$ GeV; $\Delta R_{\ell_0\ell_1} < 2.0$	$E_{T,rel}^{miss} < 40$ GeV at least one SFOS lepton pair with $ m_{\ell\ell} - m_Z < 25$ GeV
Top CR	at least one b -tagged jet with $p_T > 25$ GeV $m_{\ell\ell,min} > 12$ GeV; $\Delta R_{\ell_0\ell_1} < 2.0$	$E_{T,rel}^{miss} > 40$ GeV all SFOS lepton pairs with $ m_{\ell\ell} - m_Z > 25$ GeV

ATLAS-CONF-2012-078

	Data	MC	Data/MC	VVV	WZ*	WW	ZZ*	Z+jets	Top
WZ* CR	439	438 ± 24	1.00 ± 0.07	2.95 ± 0.13	350 ± 10	0.21 ± 0.12	48 ± 4	36 ± 13	0.8 ± 0.4
ZZ* CR	244	210 ± 40	1.15 ± 0.23	0.25 ± 0.04	12.3 ± 0.7	0.05 ± 0.05	90 ± 4	110 ± 40	0.57 ± 0.29
Z+jets CR	828	860 ± 40	0.96 ± 0.06	1.7 ± 0.1	351 ± 9	0.02 ± 0.04	290 ± 10	216 ± 30	0.50 ± 0.34
Top CR	6	6.2 ± 1.1	1.0 ± 0.4	0.15 ± 0.04	0.78 ± 0.31	0.00 ± 0.00	0.23 ± 0.08	0.13 ± 0.13	4.8 ± 0.8

ATLAS-CONF-2012-078

3-lepton analysis (CR)



3 lepton analysis (2011)

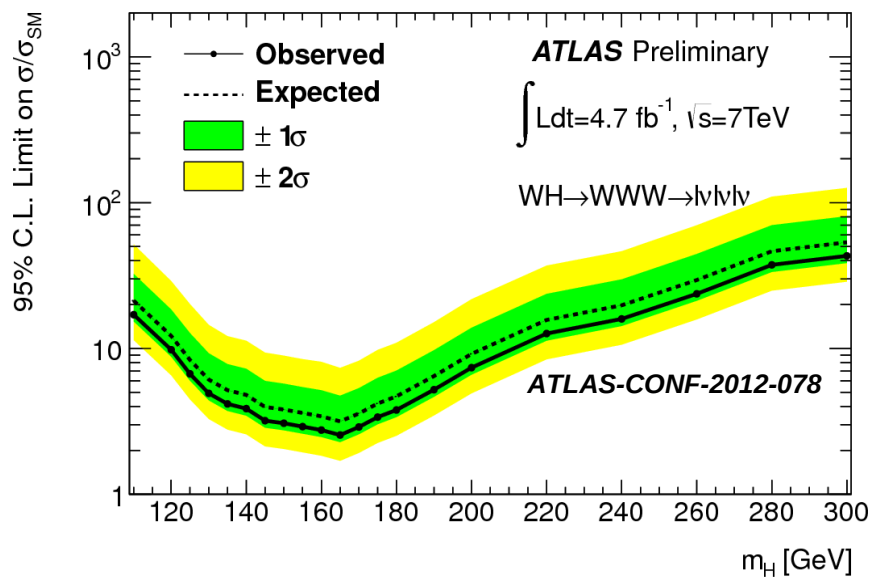
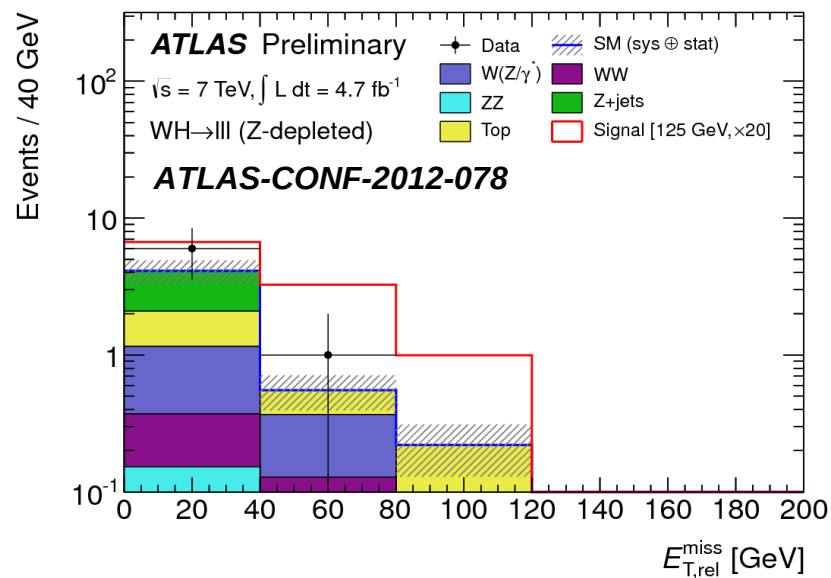
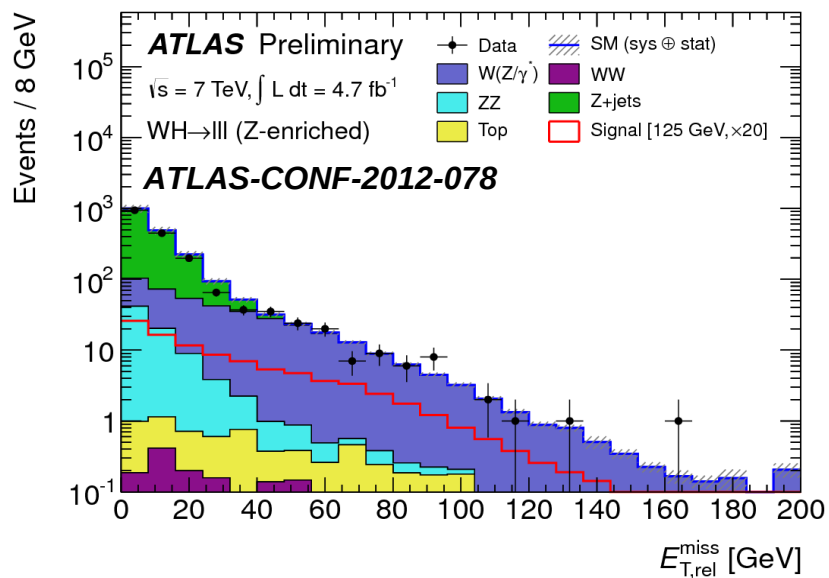
	$W(Z/\gamma^*)$	WW	ZZ	Z+jets	Top
Pre-selection	392 ± 24	2.26 ± 0.33	85 ± 7	1720 ± 230	38.6 ± 1.2
Z enriched	390 ± 23	1.84 ± 0.27	85 ± 7	1720 ± 230	30.2 ± 1.1
At most 1 jet, not b -tagged	335 ± 21	1.65 ± 0.27	75 ± 6	1550 ± 210	5.0 ± 0.5
$E_{T,rel}^{miss} > 40$ GeV	106 ± 7	0.60 ± 0.15	1.9 ± 0.4	5.2 ± 2.8	1.88 ± 0.30
Z mass veto	6.6 ± 0.7	0.39 ± 0.12	0.31 ± 0.11	1.5 ± 1.5	1.10 ± 0.22
All cuts	3.2 ± 0.8	0.09 ± 0.06	0.17 ± 0.07	--	0.28 ± 0.12
Z depleted	1.36 ± 0.15	0.42 ± 0.11	0.15 ± 0.05	2.1 ± 0.8	8.4 ± 0.6
At most 1 jet, not b -tagged	1.08 ± 0.13	0.37 ± 0.10	0.15 ± 0.05	2.0 ± 0.7	1.27 ± 0.29
$E_{T,rel}^{miss} > 25$ GeV	0.49 ± 0.07	0.17 ± 0.07	0.03 ± 0.03	--	0.52 ± 0.20
All cuts	0.21 ± 0.07	0.00 ± 0.05	0.03 ± 0.03	--	0.01 ± 0.10

ATLAS-CONF-2012-078

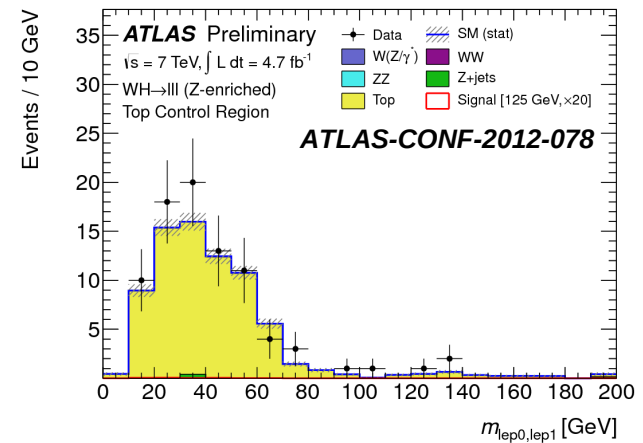
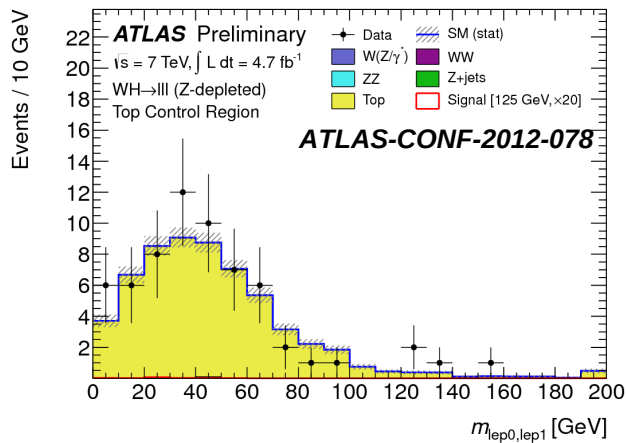
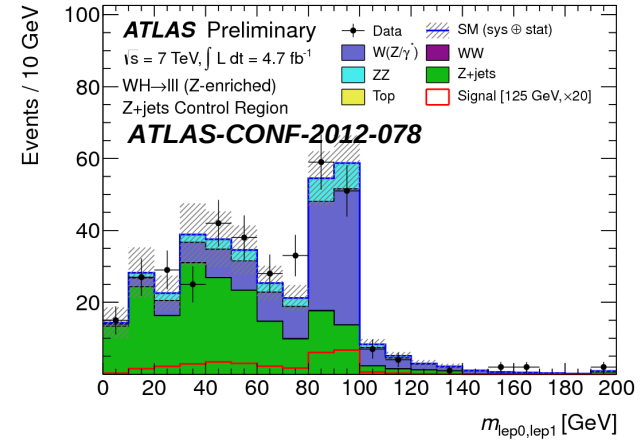
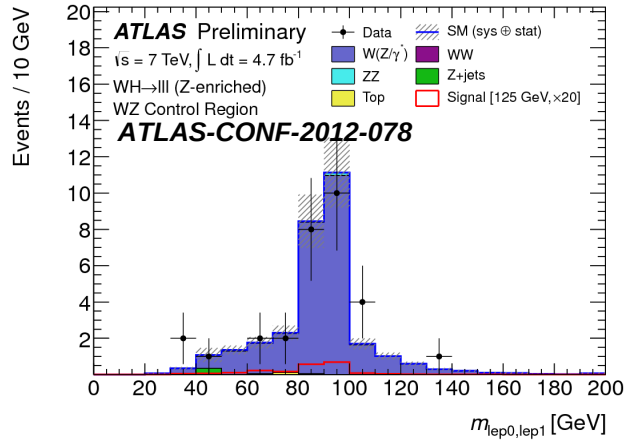
CR	Observed	Expected	Data/MC	$W(Z/\gamma^*)$	WW + ZZ	Z+jets	Top
<i>Z enriched : WZ</i>	30	31 ± 5	0.98 ± 0.25	30 ± 5	0.52 ± 0.17	0.4 ± 0.4	0.16 ± 0.10
<i>Z enriched : Z + jets</i>	365	360 ± 80	1.02 ± 0.23	127 ± 21	32 ± 7	200 ± 50	0.52 ± 0.15
<i>Z enriched : Top</i>	84	75.2 ± 1.9	1.12 ± 0.13	0.10 ± 0.04	0.10 ± 0.12	0.5 ± 0.4	74.4 ± 1.8
<i>Z depleted : Top</i>	63	59.3 ± 1.6	1.06 ± 0.14	0.04 ± 0.02	0.05 ± 0.03	0.09 ± 0.09	59.1 ± 1.6

ATLAS-CONF-2012-078

3-lepton analysis (2011)



3-lepton analysis (2011)



4 lepton analysis

	ZZ	VVV	Fakes	Total Bkg.	$VH(125)$	Data
4 leptons	164 ± 6	1.89 ± 0.08	8.8 ± 5.8	175 ± 10	0.89 ± 0.04	182
E_T^{miss} and p_T	41.8 ± 1.6	1.65 ± 0.07	7.8 ± 5.3	51.3 ± 5.6	0.71 ± 0.03	55
Jet multiplicity and b -veto	30.8 ± 1.1	1.30 ± 0.06	0.31 ± 0.11	32.5 ± 1.2	0.52 ± 0.02	35
Mass cuts	2.97 ± 0.15	0.22 ± 0.02	0.05 ± 0.03	3.24 ± 0.16	0.41 ± 0.02	2
Angular cut	1.88 ± 0.12	0.20 ± 0.02	0.04 ± 0.02	2.12 ± 0.12	0.39 ± 0.02	2
1 SFOS pair	0.24 ± 0.04	0.08 ± 0.01	0.00 ± 0.01	0.33 ± 0.05	0.19 ± 0.01	2
Overlap removal	0.23 ± 0.04	0.08 ± 0.01	0.00 ± 0.01	0.32 ± 0.05	0.18 ± 0.01	2
2 SFOS pairs	1.64 ± 0.11	0.12 ± 0.01	0.04 ± 0.02	1.79 ± 0.11	0.20 ± 0.01	0
4ℓ system cuts	0.72 ± 0.07	0.11 ± 0.01	0.04 ± 0.02	0.86 ± 0.08	0.18 ± 0.01	0
Overlap removal	0.70 ± 0.07	0.10 ± 0.01	0.04 ± 0.02	0.84 ± 0.08	0.17 ± 0.01	0

ATLAS-CONF-2012-078

4 lepton analysis

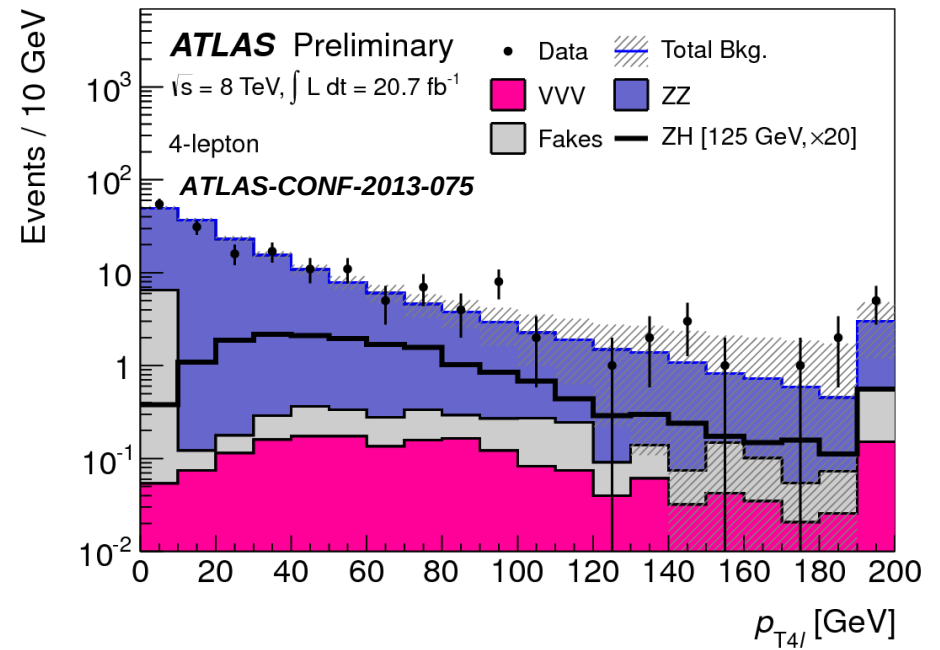
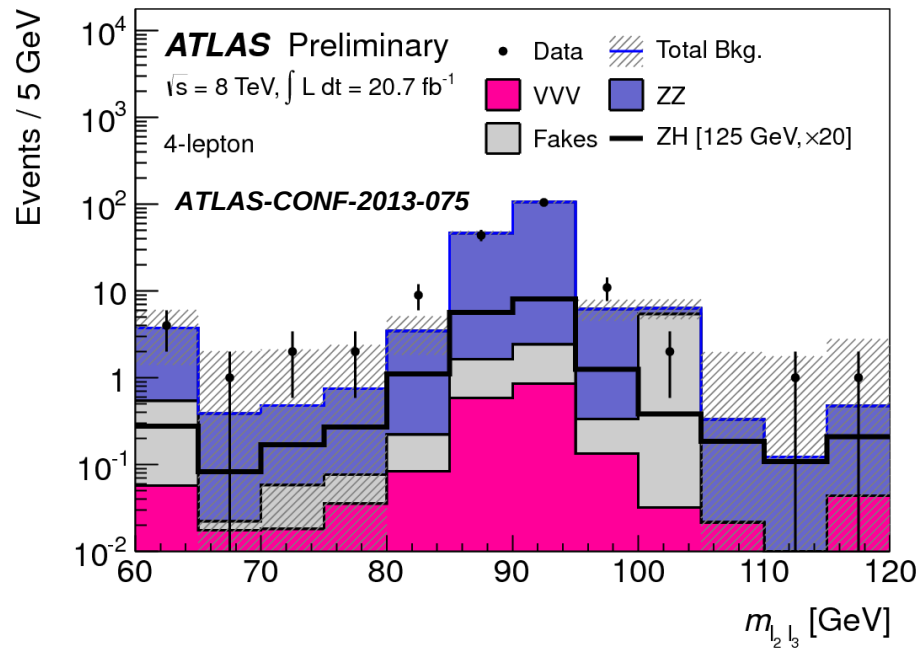
	Selection
ZZ CR	2 SFOS pairs of isolated leptons highest p_T lepton: $p_T > 25$ GeV second highest p_T lepton: $p_T > 20$ GeV third highest p_T lepton: $p_T > 15$ GeV fourth highest p_T lepton: $p_T > 10$ GeV at most one jet with $p_{T,\text{jet}} > 25$ GeV no b -tagged jets with $p_T > 25$ GeV $ m_{\ell_2\ell_3} - m_Z < 10$ GeV $m_{\ell_0\ell_1} > 65$ GeV overlap removal with dilepton analysis

ATLAS-CONF-2012-078

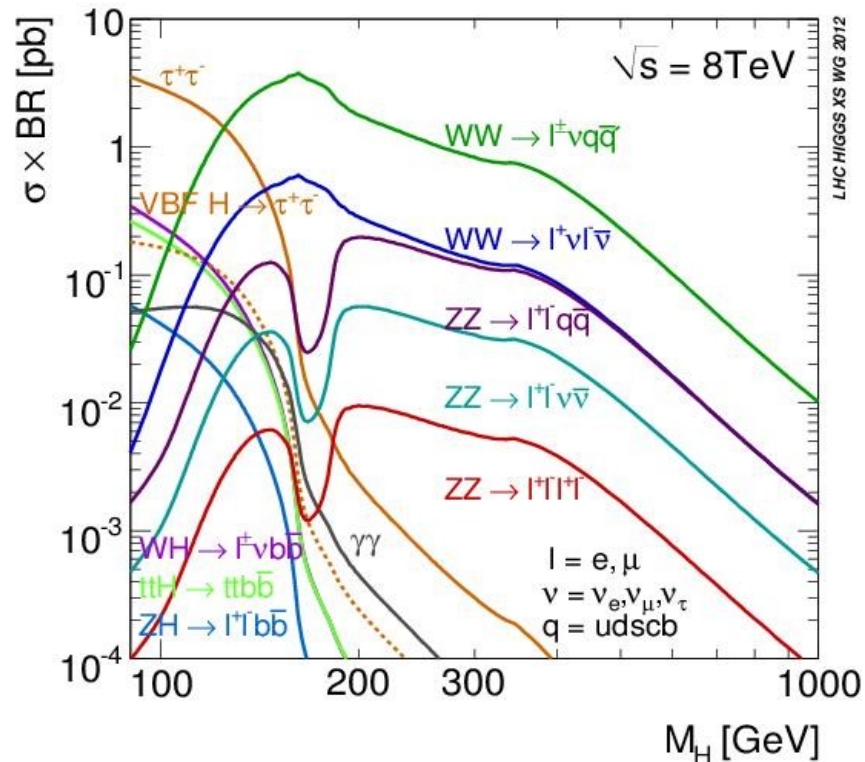
	$Z(H \rightarrow WW)$	Data	MC	Data/MC	ZZ*	Top	VVV	WZ*	Z+jets
ZZ CR	0.03 ± 0.00	100	100.00 ± 3.19	1.00 ± 0.10	99.42 ± 3.19	0.03 ± 0.02	0.55 ± 0.03	0.00 ± 0.01	0.00 ± 0.01

ATLAS-CONF-2012-078

4-lepton analysis

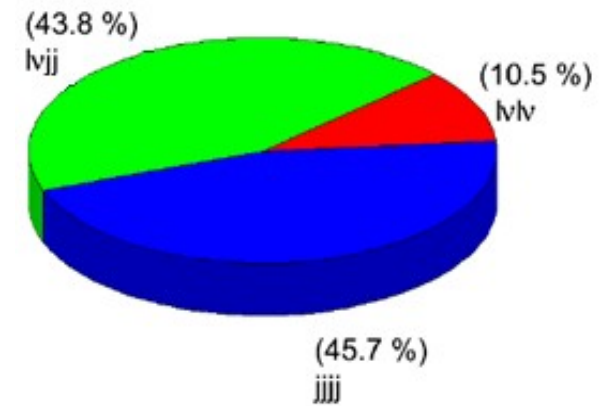


The Standard Model Higgs boson



<https://twiki.cern.ch/twiki/bin/view/LHCPhysics/CrossSections>

WW BR



The total leptonic final state it is easier to analyse due a more clear signature of the event