Search for the Higgs boson in VH(H→bb) channel using the ATLAS detector

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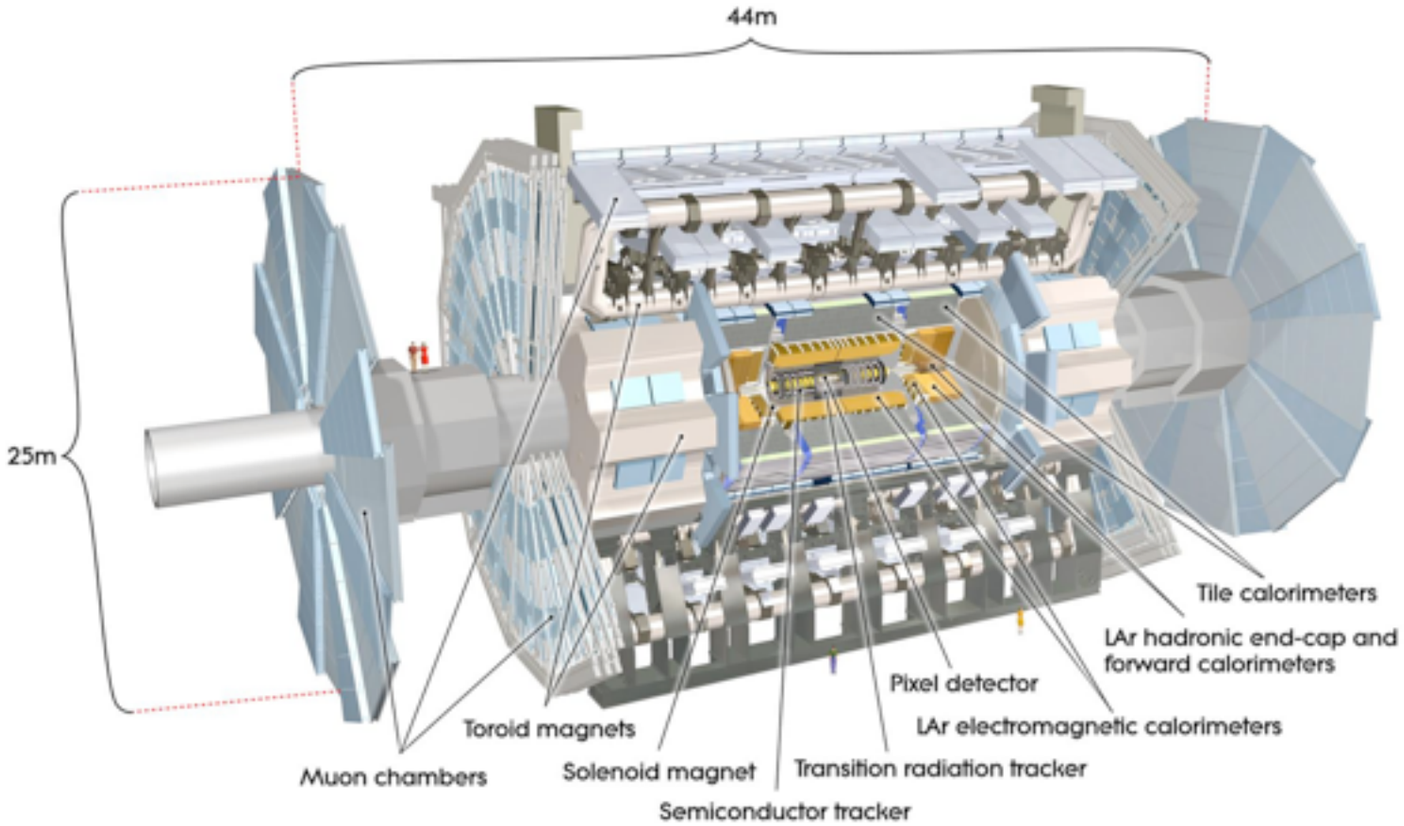
On behalf of the ATLAS collaboration

IFAE Barcelona

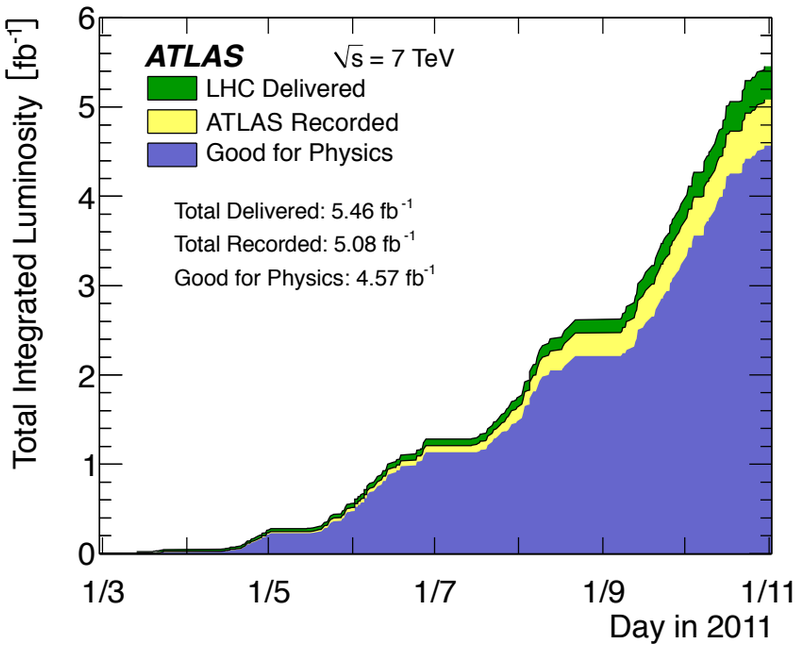
V CPAN Days 2013
Santiago de Compostela

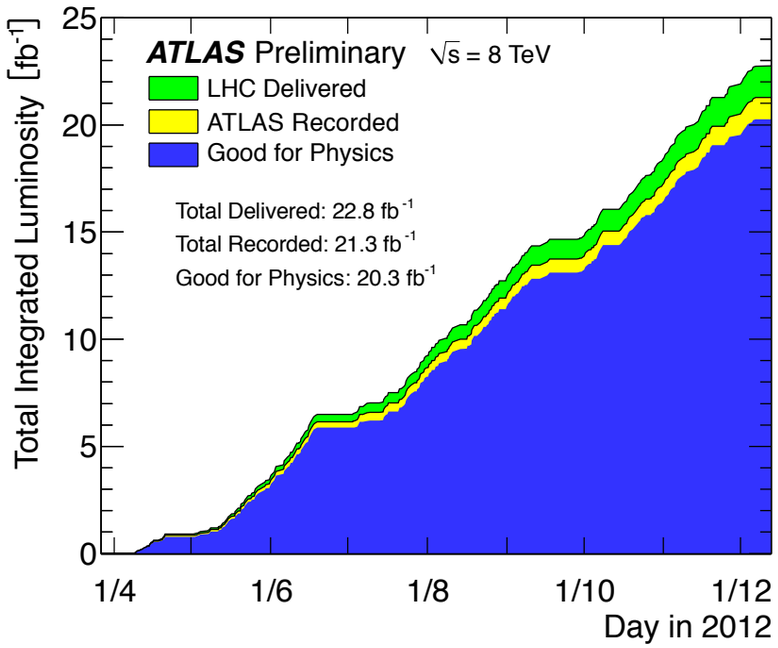
A Toroidal LHC ApparatuS (ATLAS)



ATLAS is divided in different subdetectors.
Complexity of the analysis VH(H→bb) requires good performance of all of them.

~5 fb^{-1} at 7 TeV
~21 fb^{-1} at 8 TeV.
Full data sets are used in the analysis.



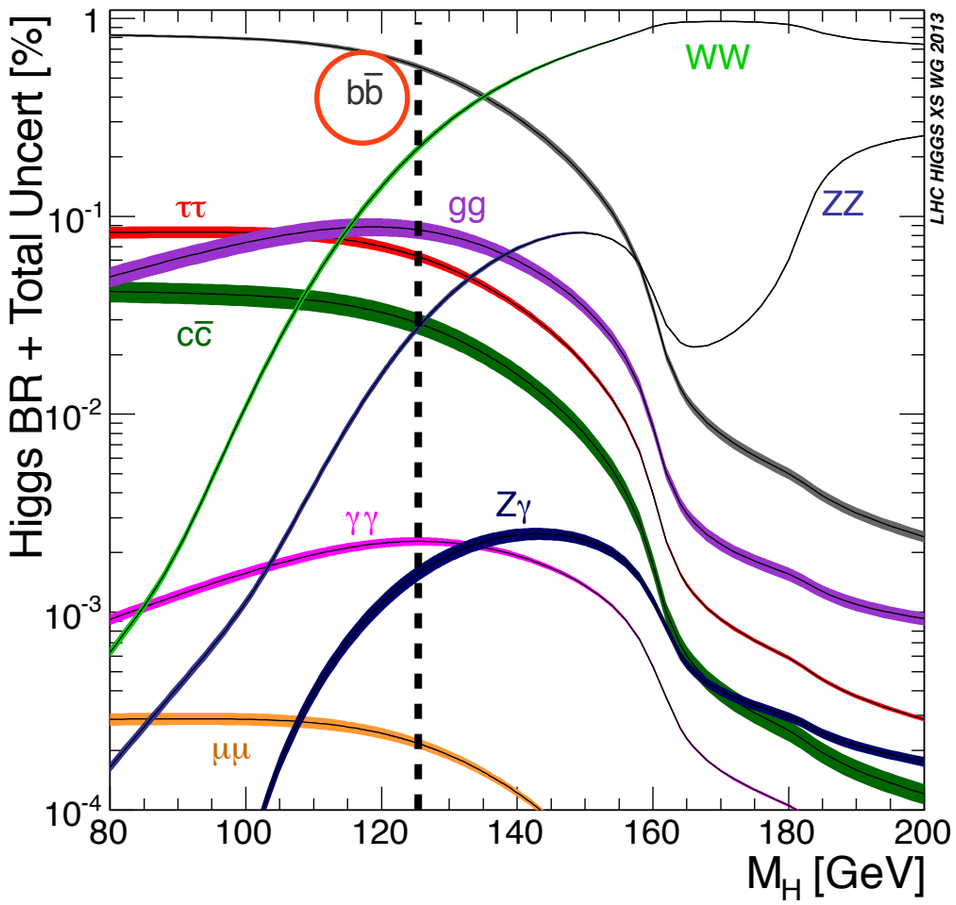


Introduction

The discovery and the properties of the Higgs boson particle has been driven mainly by analyses using bosonic decay modes ($H\to\gamma\gamma$, $H\to ZZ\to 4l$, $H\to WW\to l\nu l\nu$).

It is also crucial to study the **fermionic couplings** of the Higgs to:

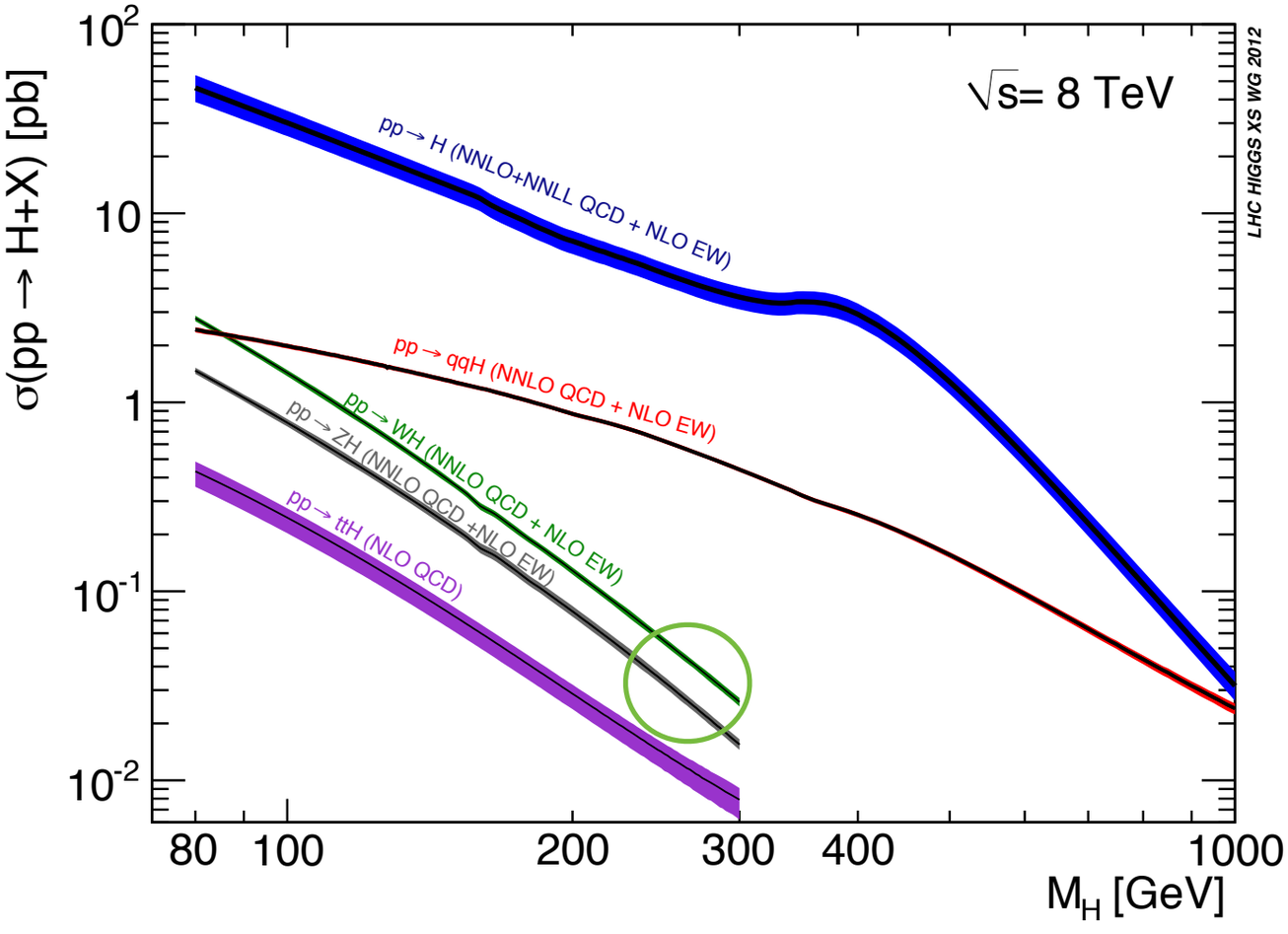
- Understand the properties of the new particle discovered.
- Test for potential BSM physics.



For studying Higgs direct coupling to fermions the **H→bb** is one of the most promising channels.

Introduction VH (H→bb)

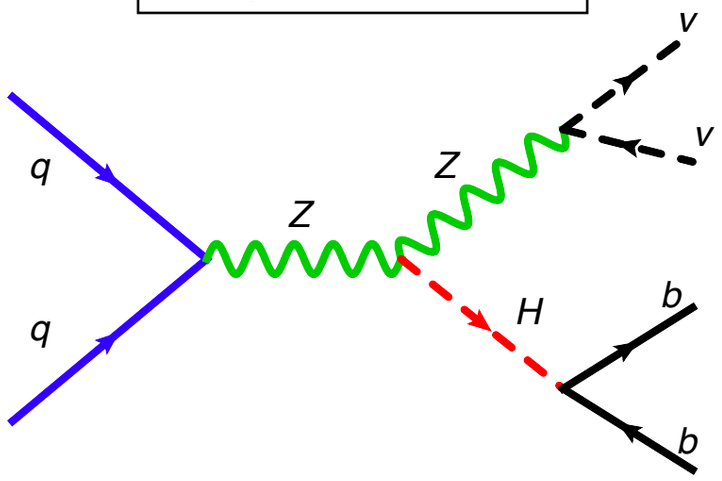
The H→bb inclusive analysis is overwhelmed by the large multi-jet background at LHC. Thus, the association with W/Z boson is the most promising decay mode for searching for H→bb.



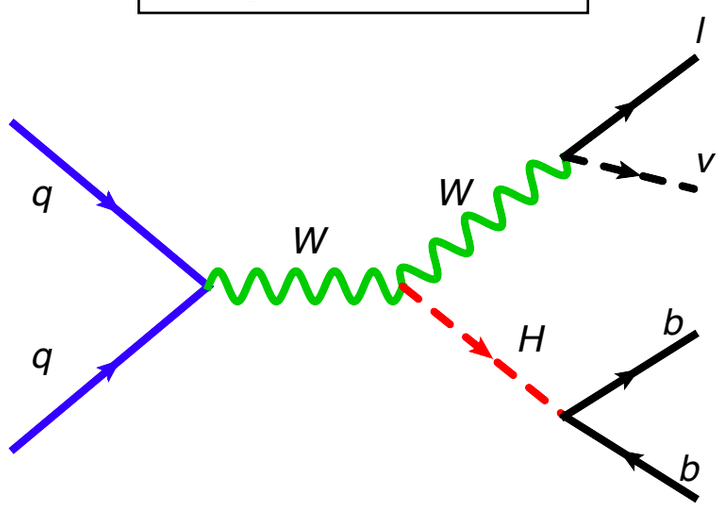
VH (H→bb)

3 channels are simultaneously explored ($Z\to\nu\nu$, $Z\to ll$, $W\to l\nu$) and combined to increase sensitivity.

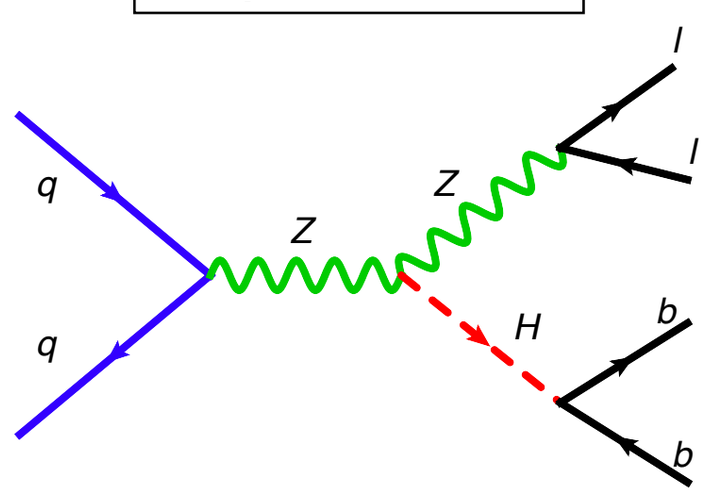
0 lepton channel



1 lepton channel



2 lepton channel

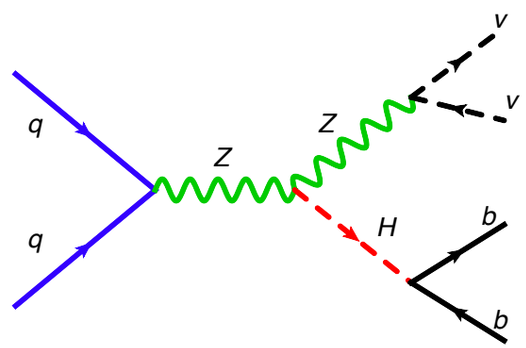


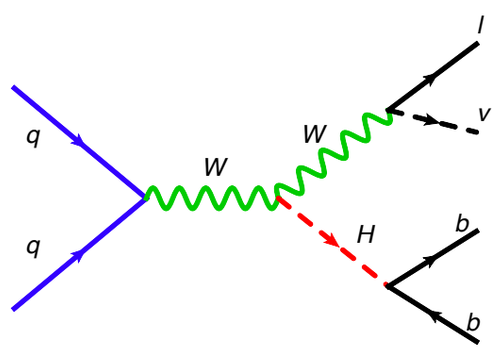
VH (H→bb) Event selection

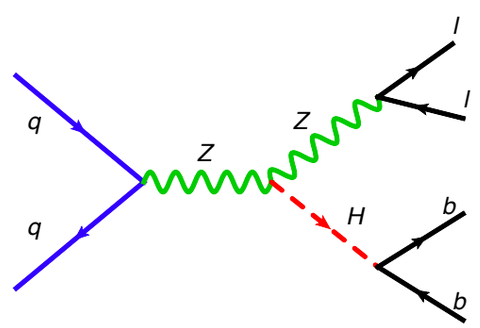
0-lepton cuts
- No loose leptons
- E_T^{Miss} > 120 GeV
- QCD rejection cuts

1-lepton cuts
- 1 tight lepton
- No additional leptons
- QCD rejection
- m_T^W > 40 GeV (if p_T^W < 160)
- E_T^{Miss} > 50 GeV (if p_T^W > 200)

2-lepton cuts
- 1 medium+1 loose lepton
- No additional leptons
- 83 < m_{ll} < 99
- E_T^{Miss} < 60 GeV







Exactly two jets tagged with MV1 tagger with btag effciency of 70%.
E_T^{Miss} > 25 GeV
ΔR cuts between the two jets exploit the different signal and background kinematics:

lepton = e, μ

p_T^V bin (GeV)	0-90	90-120	120-160	160-200	> 200
ΔR(j,j)	0.7-3.4	0.7-3.0	0.7-2.3	0.7-1.8	< 1.4

ATLAS-CONF-2013-07 (p.13)

Backgrounds

MC generators

WH/ZH PYTHIA8

ttbar POWHEG+PYTHIA

Single Top ACER/POWHEG+PYTHIA

Z/W+jets SHERPA

Diboson (WW,WZ,ZZ) HERWIG

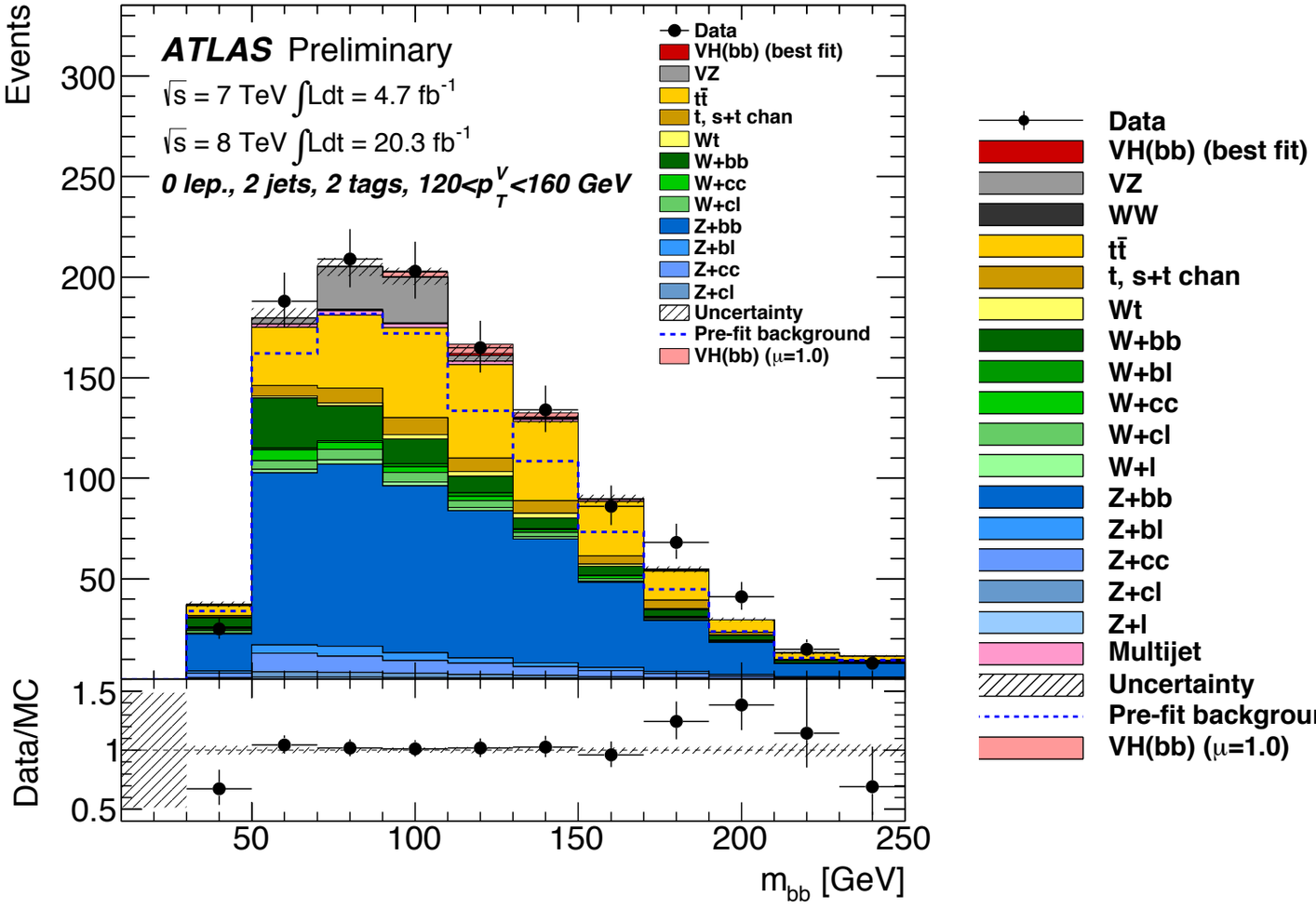
Multijet background

Data driven methods have been used to estimate the fraction of QCD events:

0 lepton: 1%.

1 lepton: 15% - <1%.

2 lepton: negligible.



VH (H→bb) strategy

		2jets, 1-tags	3jets, 1-tags	2jets, 2-tags	3jets, 2-tags	Top emu CR
3 VpT bins	0-lepton	Norm	Norm	**Shape**	Shape	-
5 VpT bins	1-lepton	Norm	Norm	**Shape**	Shape	-
5 VpT bins	2-lepton	Norm	Norm	**Shape**	Shape	**Norm**

p^{V}_{T} CR

mbb SR

VH (H→bb) strategy

		2jets, 1-tags	3jets, 1-tags	2jets, 2-tags	3jets, 2-tags	Top emu CR
3 VpT bins	0-lepton	Norm	Norm	**Shape**	Shape	-
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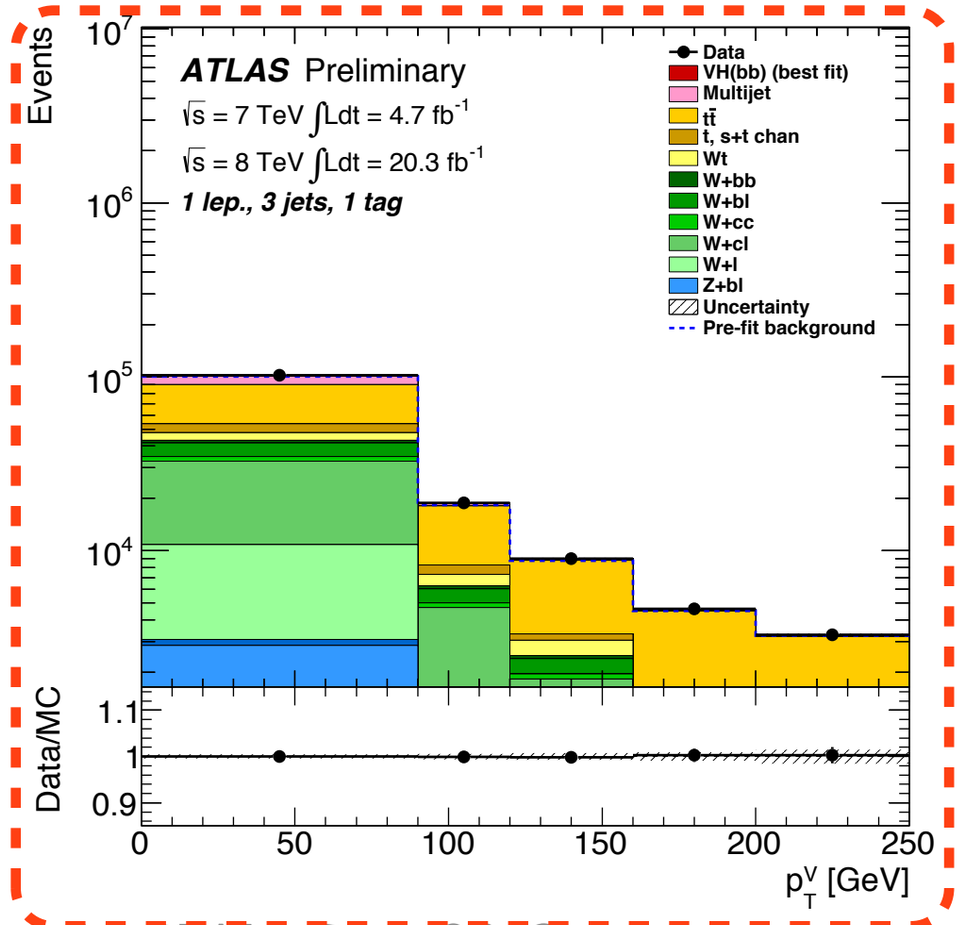
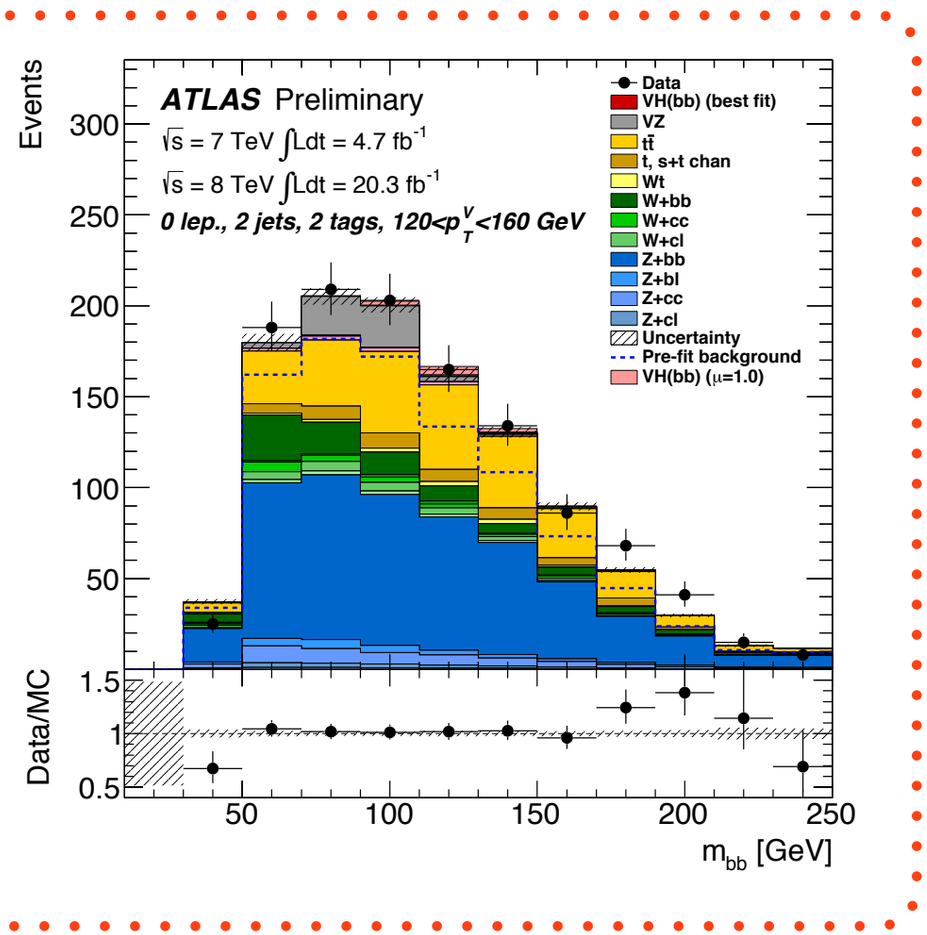
5 VpT bins	2-lepton	Norm	Norm	**Shape**	Shape	**Norm**
		p^V_T CR		mbb SR		





VH (H→bb) strategy

		2jets, 1-tags	3jets, 1-tags	2jets, 2-tags	3jets, 2-tags	Top emu CR
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5 VpT bins	1-lepton	Norm	Norm	**Shape**	Shape	-
5 VpT bins	2-lepton	Norm	Norm	**Shape**	Shape	**Norm**

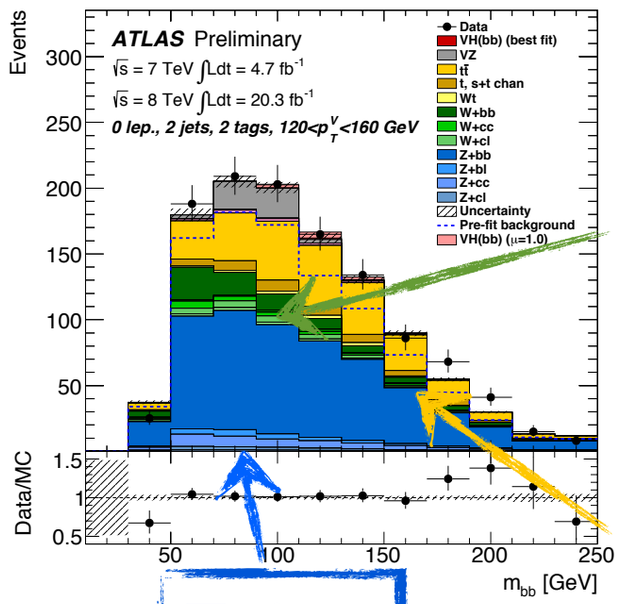
Simultaneous fit to the 3 channels and all regions

Coherent normalization among the channels and regions:

- Float in fit: V+cl, V+bl, V+bb/cc and ttbar.
- Fixed to MC: diboson, single top and V+light jets.

VH (H→bb) strategy

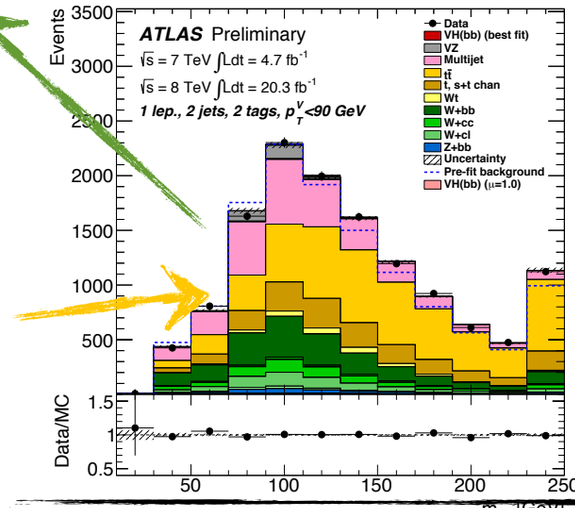
mbb **0 lepton** 2tag2jet 120< V_{pT} <160



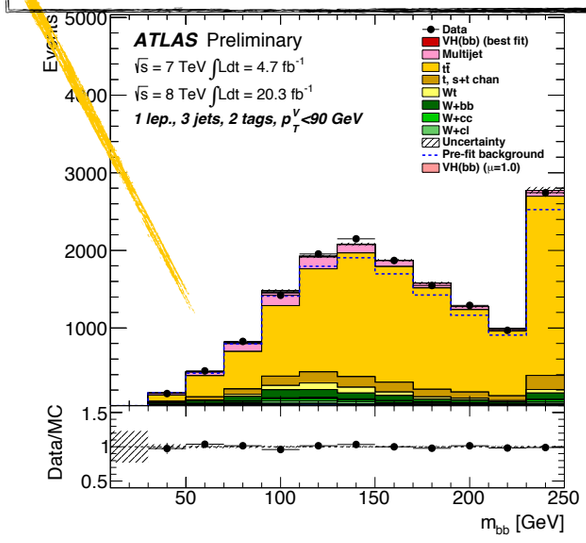
W+jets

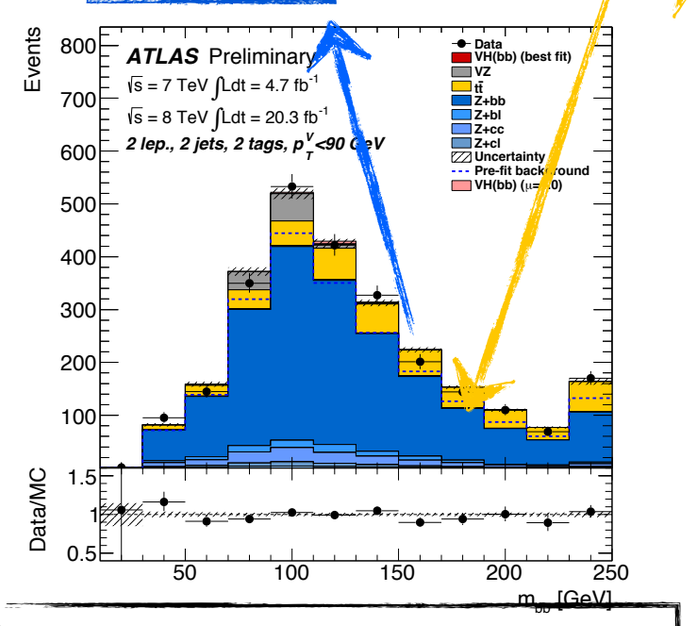
Top

Z+jets



mbb **1 lepton** 2tag2/3jet V_{pT} <90 GeV





mbb **2 lepton** 2tag2jet V_{pT} <90 GeV

	2jets, 1-tags	3jets, 1-tags	2jets, 2-tags	3jets, 2-tags	Top emu CR
3 VpT bins	0-lepton Norm	Norm	**Shape**	Shape	-
5 VpT bins	1-lepton Norm	Norm	**Shape**	Shape	-
5 VpT bins	2-lepton Norm	Norm	**Shape**	Shape	**Norm**

Simultaneous fit to the 3 channels and all regions

Coherent normalization among the channels and regions:

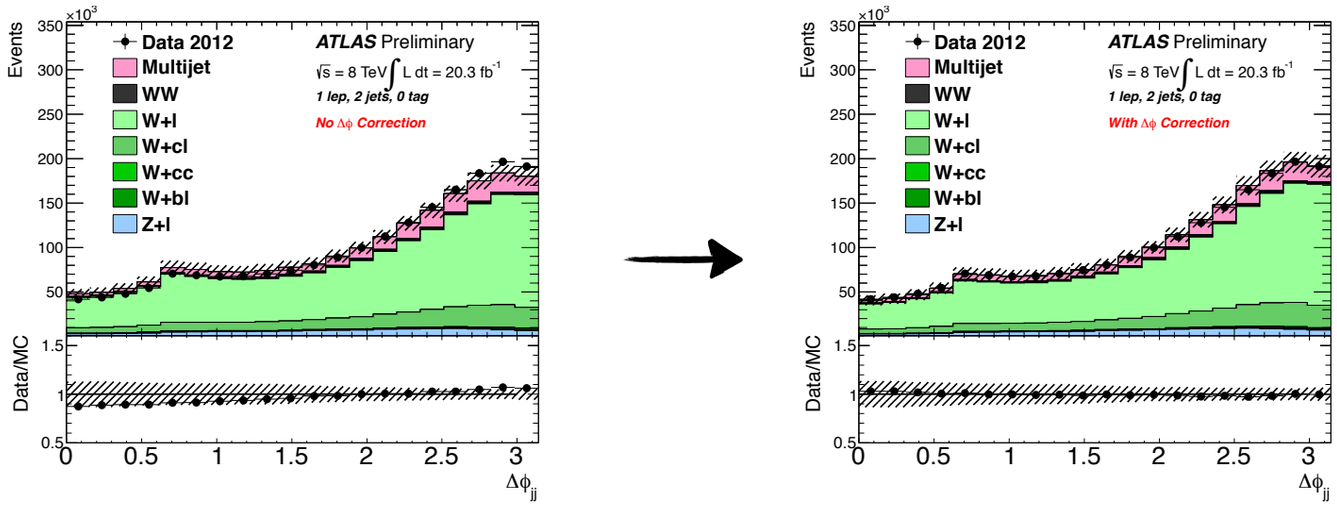
- Float in fit: V+cl, V+bl, V+bb/cc and ttbar.
- Fixed to MC: diboson, single top and V+light jets.

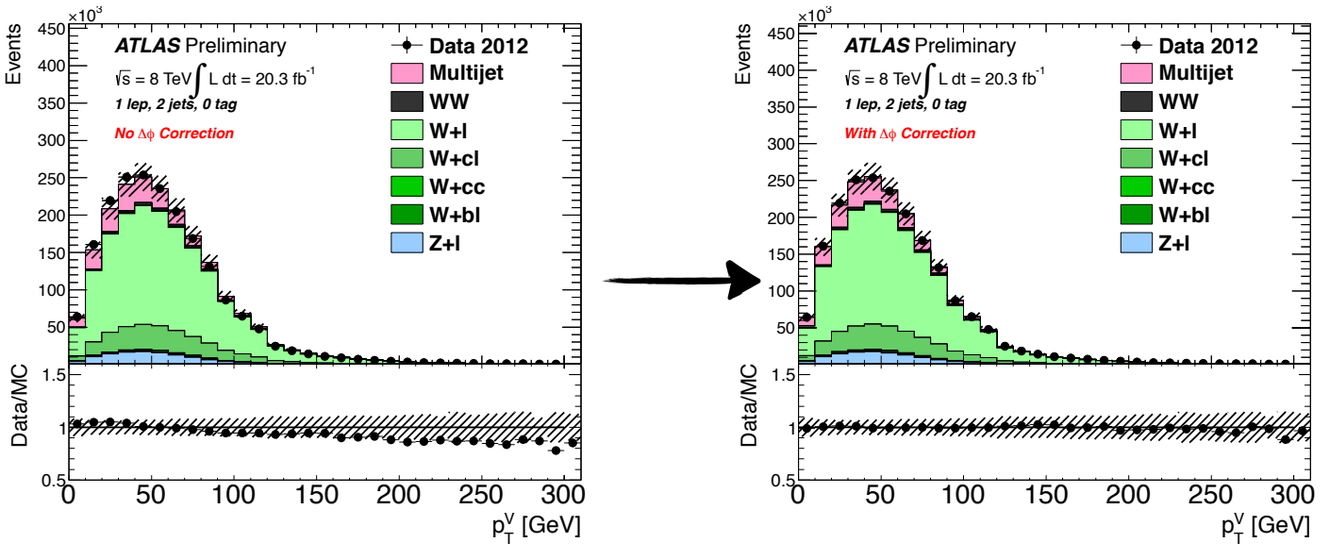
Systematic uncertainties

- **Experimental uncertainties:**
  - Luminosity.
  - Trigger.
  - Muon and Electrons identification and energy.
  - MET.
  - Jet vertex fraction (pileup jets discriminator).
  - Jet energy scale and resolution.
  - B-tagging.
- **Background Modeling:**
  - Mbb shape.
  - 3 to 2 jets normalization.
  - p^{V}_{T} shape.
  - $\Delta\phi$ and top pt reweighting.
  - Flavor composition in V+jets.
  - Normalization on dibosons, single top.
- **Theoretical + acceptance uncertainties for WH and ZH.**

Δϕ reweighting

Δϕ between the two leading jets of the event





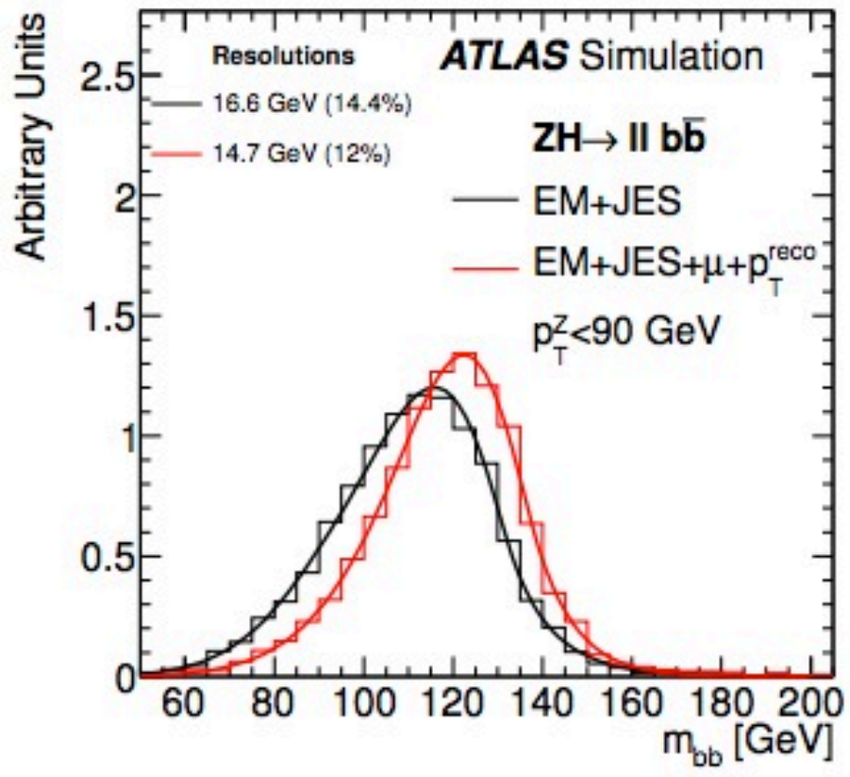
Correction derived from data

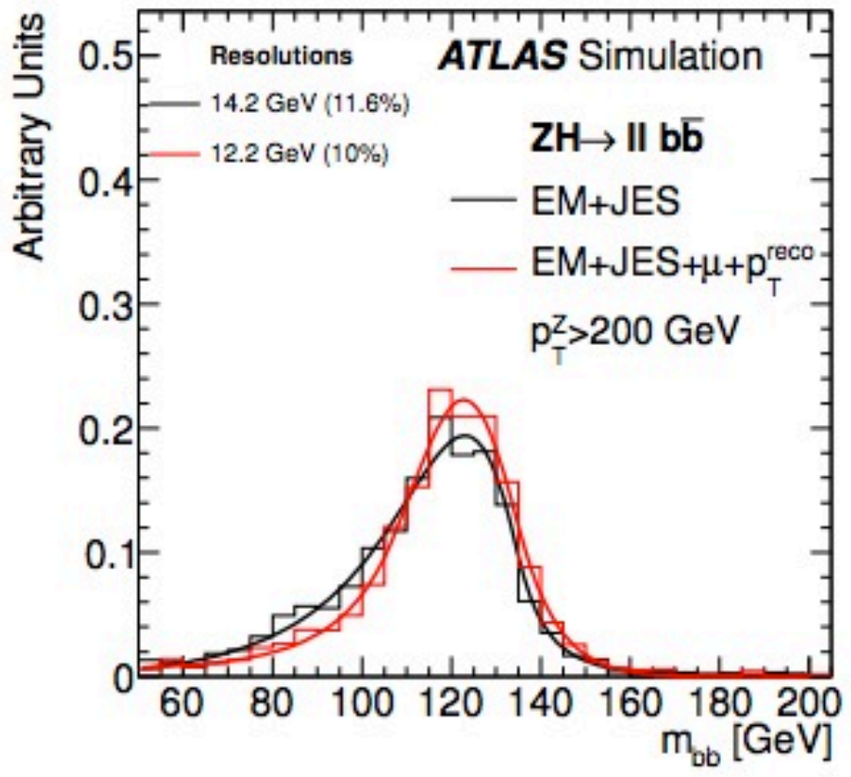
V+jets samples are corrected => this improves agreement in other distributions. 50 % of the correction is applied as systematic.

Invariant mass (mbb) resolution

Jet energies used to computed mbb invariant mass is corrected for:

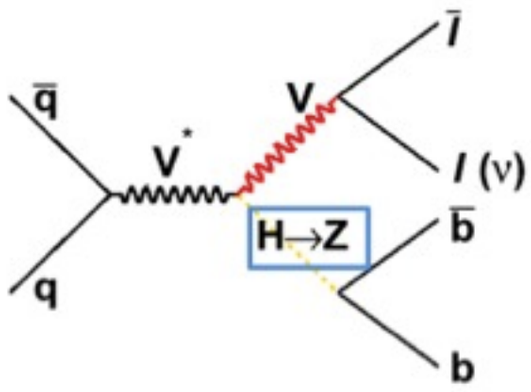
- μ's inside jets arising from semileptonic b-decays.
- resolution effects specific to the kinematics of the decay of Higgs boson (125 GeV).



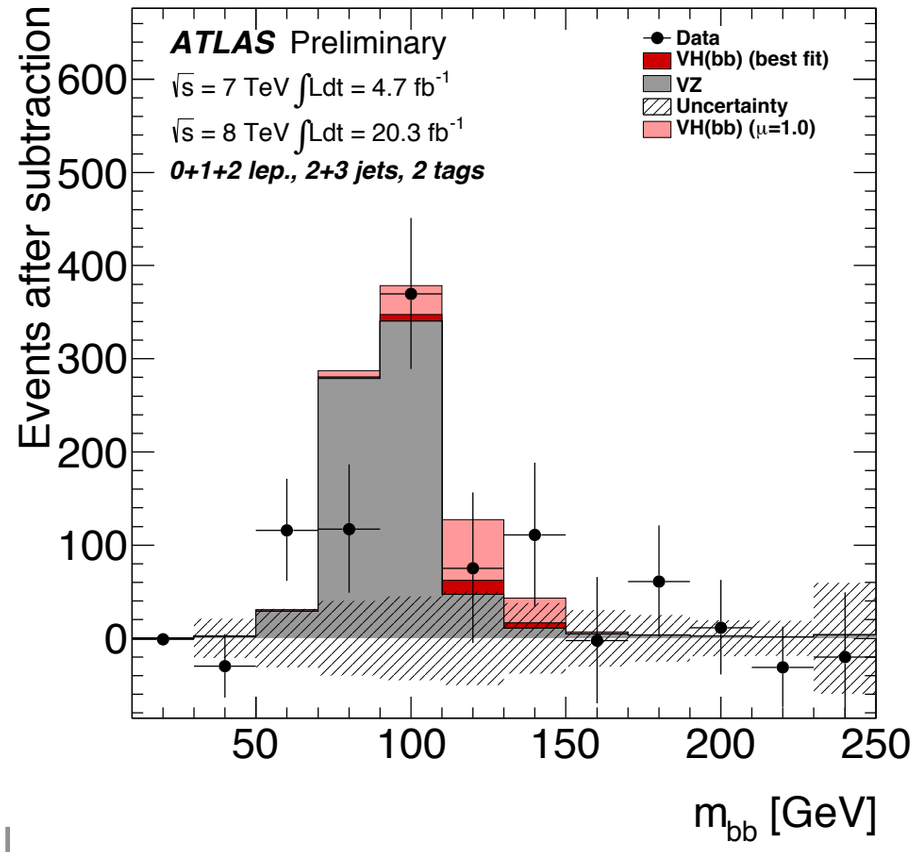


VZ (Z→bb) diboson results

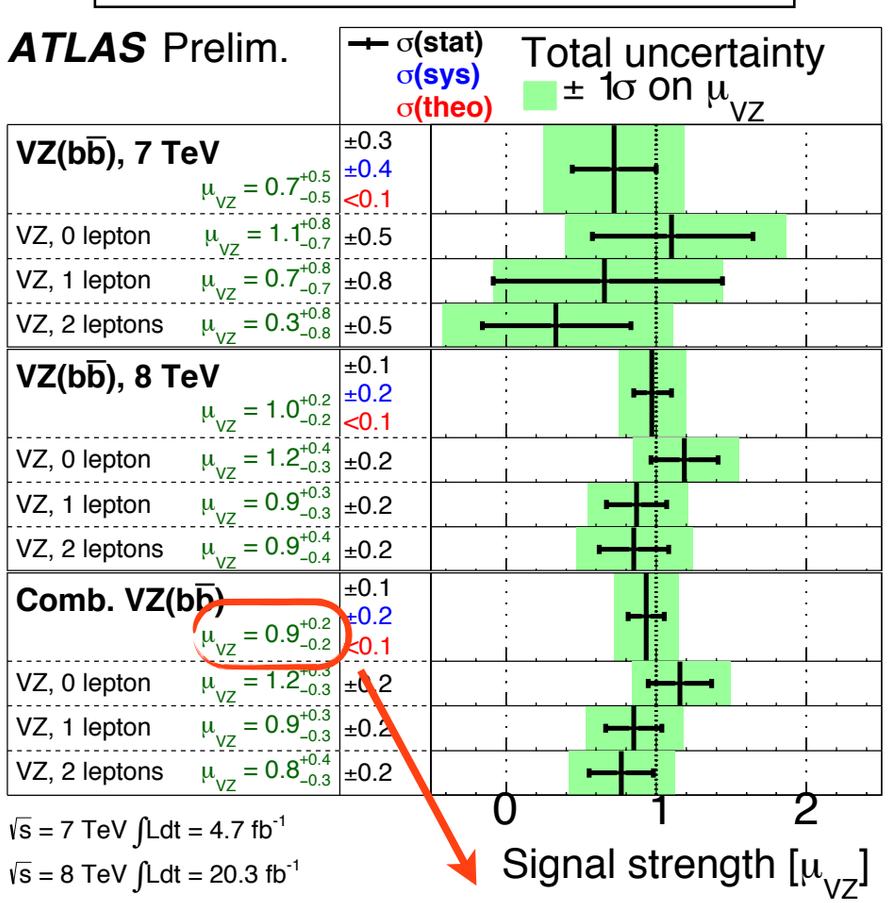
VZ has a similar signature with **5 times larger** cross section than VH (H→bb) → perfect to validate Higgs analysis.



$$\mu = \frac{\sigma_{\text{meas}}}{\sigma_{\text{SM}}}$$



μVZ PER CHANNEL AND YEAR



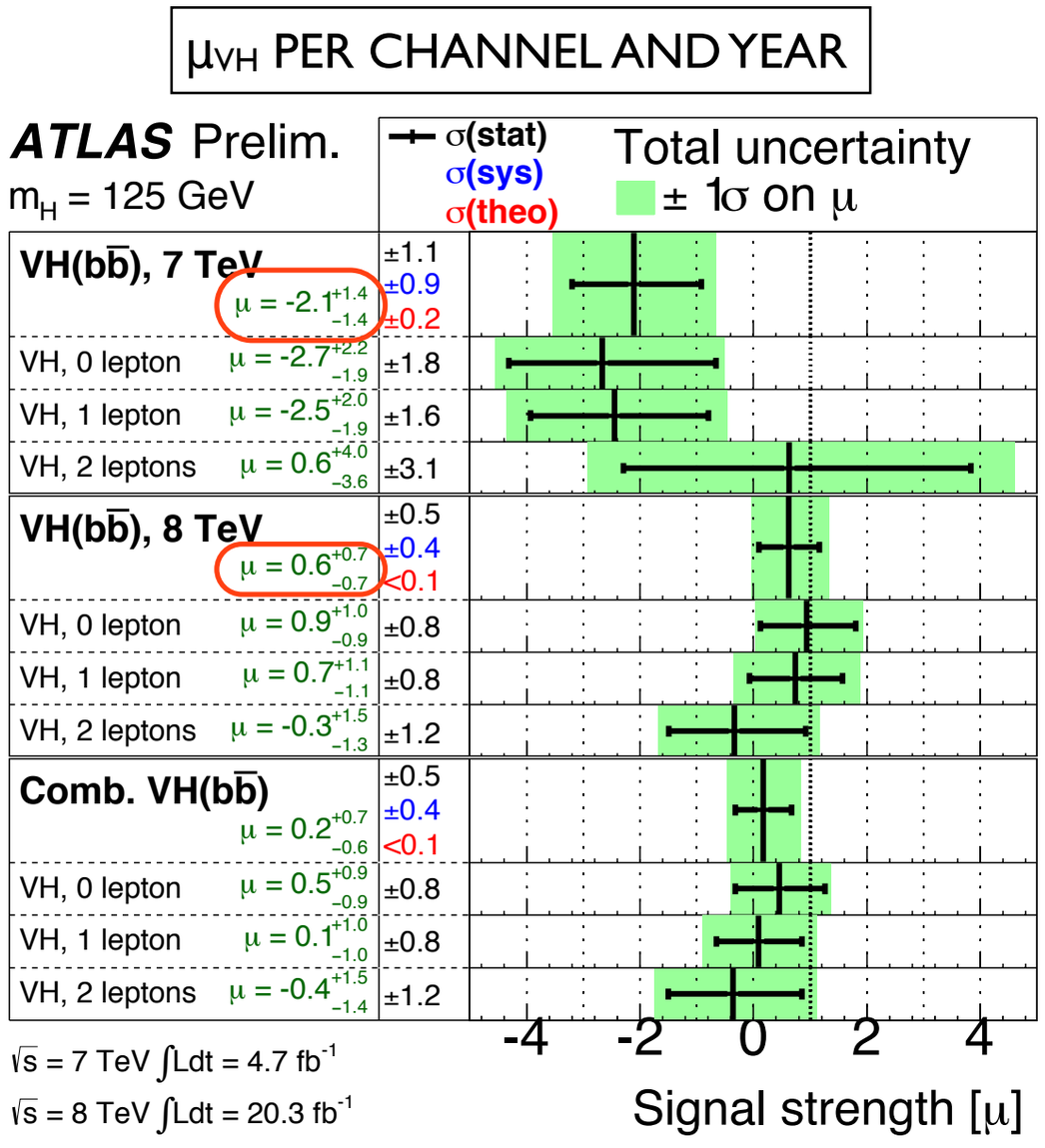
$$\mu_{VZ} = 0.9^{+0.2}_{-0.2}$$

Obs. (exp.) VZ p_0 = 4.8 (5.1) σ

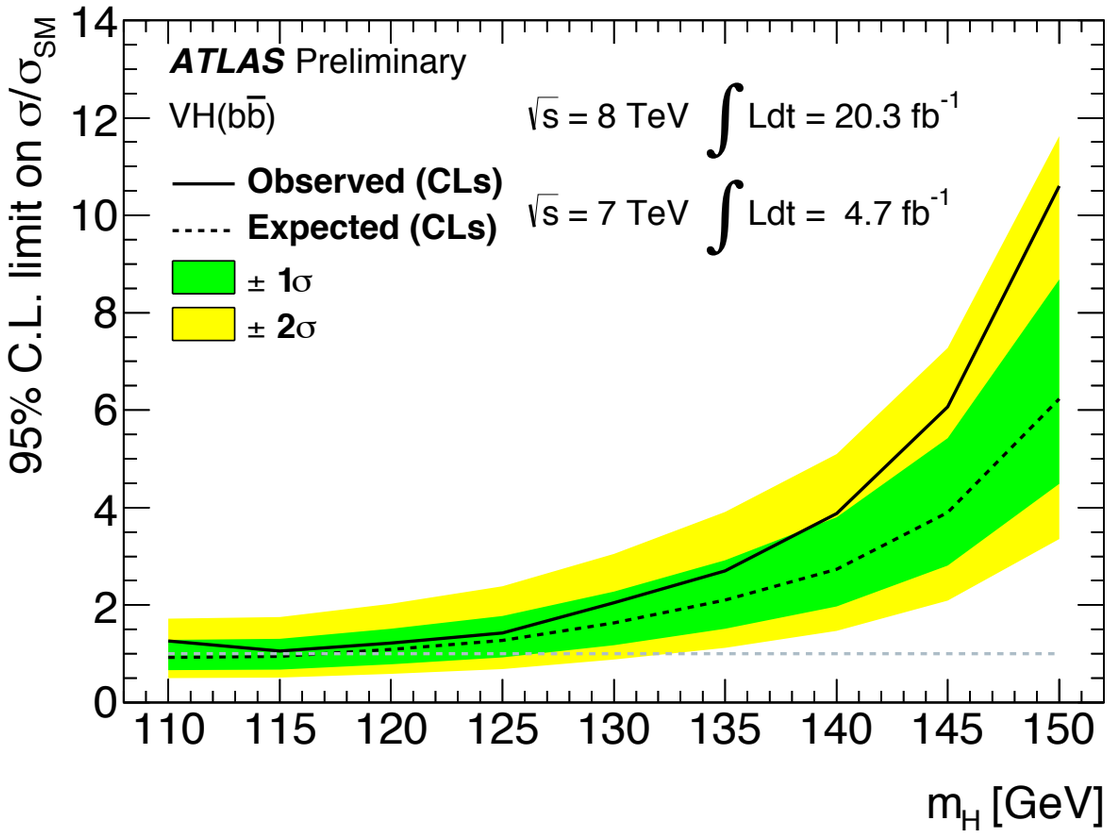
VH (H→bb) results

$$\mu = \frac{\sigma_{\text{meas}}}{\sigma_{\text{SM}}}$$

- 7 TeV has a 2 σ deficit with respect to SM expectation.
- 8TeV is consistent with Higgs and background only hypothesis within 1σ.
- Combination: $\mu = 0.2^{+0.7}_{-0.6}$



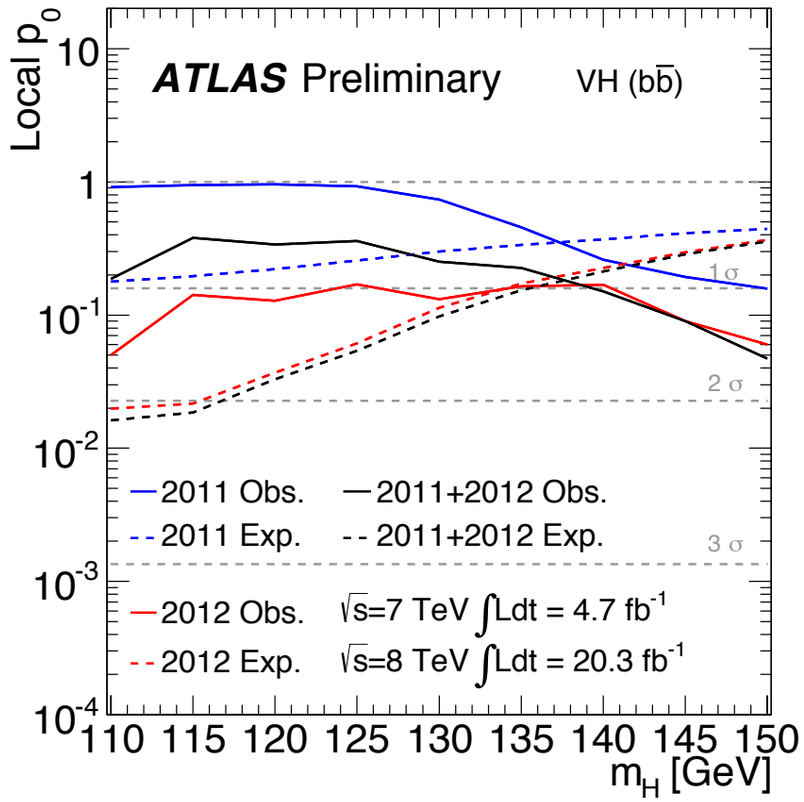
VH (H→bb) results



Observed (expected) 95 % CL limit on σ/σSM at mH=125 GeV: 1.4 (1.3)

35 % improvement excluding the increase in integrated luminosity.

More information:
ATLAS-CONF-2013-07



7 TeV data deficit drives a rather small excess compared with the SM p0 expectation.

Compatibility with μ=0 : 36 %
Compatibility with μ=1 : 11 %

Summary

- One of the most promising search for Higgs decay into fermions has been presented:
  VH (H→bb): 4.7 fb^{-1} at 7 TeV + 20.9 fb^{-1} at 8 TeV.

- Analysis is approaching the SM sensitivity values:
  VH (H→bb): obs (exp)σ/σ_{SM} at m_H=125 GeV: **1.4 (1.3)**

- More information can be found in the following link:
  VH (H→bb) (ATLAS-CONF-2013-07)

Future improvements to come stay tuned.

Back slides

VH (H→bb) Event selection

Common Selection

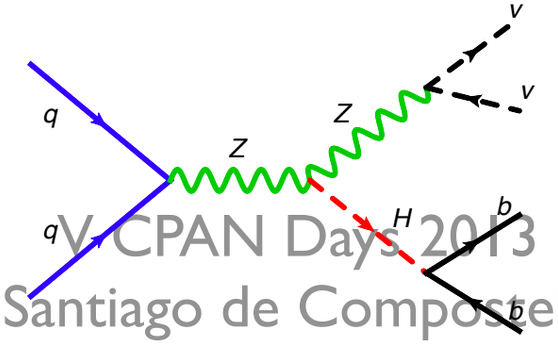
At least 2 jets, pT1 > 45, pT2 > 20 GeV
Forward jet pT > 30 GeV ("veto" jets only in 0 and 1 lepton)
Loose lepton pT > 10 GeV
Tight/Medium lepton pT > 25 GeV
Exactly two jets tagged with MV1 @ 70% working point
E_T^{Miss} > 25 GeV
ΔR cuts consistent across channels:

lepton = e, μ

p_T^V bin (GeV)	0-90	90-120	120-160	160-200	> 200
ΔR(j,j)	0.7-3.4	0.7-3.0	0.7-2.3	0.7-1.8	< 1.4

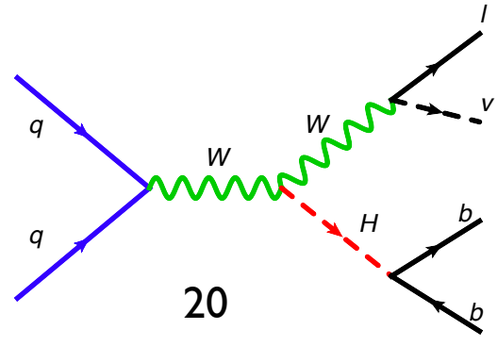
0-lepton cuts
- No loose leptons
- E_T^{Miss} > 120 GeV
- p_T^{Miss} > 30 GeV

QCD rejection
- Δphi (E_T^{Miss} ,jets) > 1.5
- Δphi (E_T^{Miss} , p_T^{Miss}) < pi/2
- Δphi (E_T^{Miss} ,bb) > 2.8

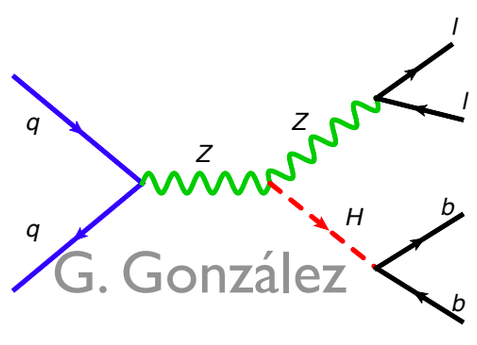


1-lepton cuts
- 1 tight lepton
- No additional leptons
- E_T^{Miss} > 25 GeV
- m_T^W < 120 GeV

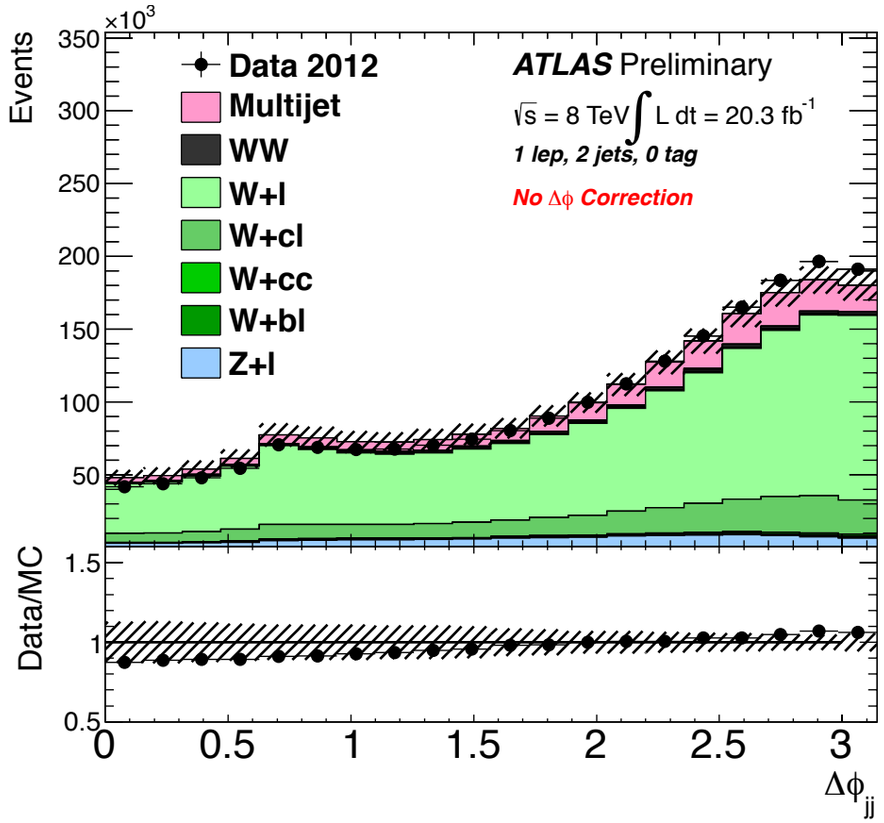
QCD rejection
- m_T^W > 40 GeV (if p_T^W < 160)
- E_T^{Miss} > 50 GeV (if p_T^W > 200)

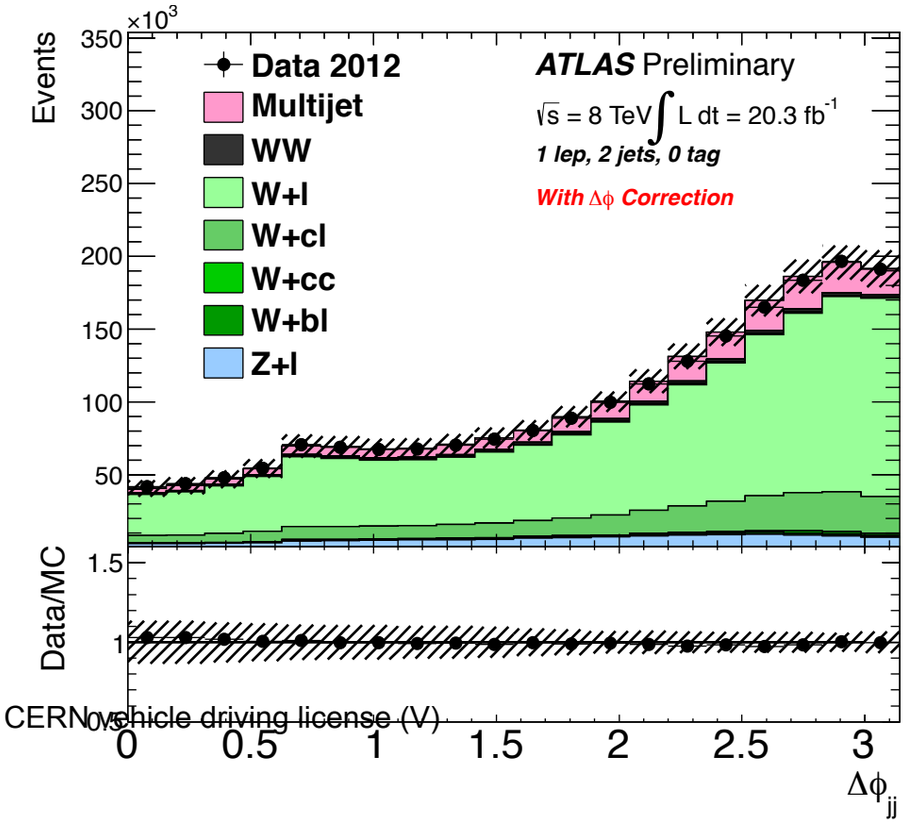


2-lepton cuts
- 1 medium+1 loose lepton
- No additional leptons
- 83 < m_{ll} < 99
- E_T^{Miss} < 60 GeV

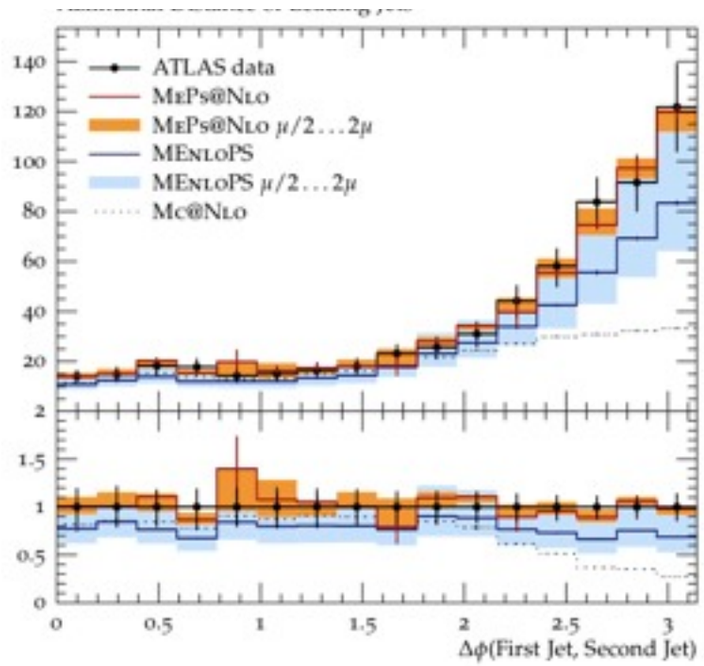


Δϕ reweighting



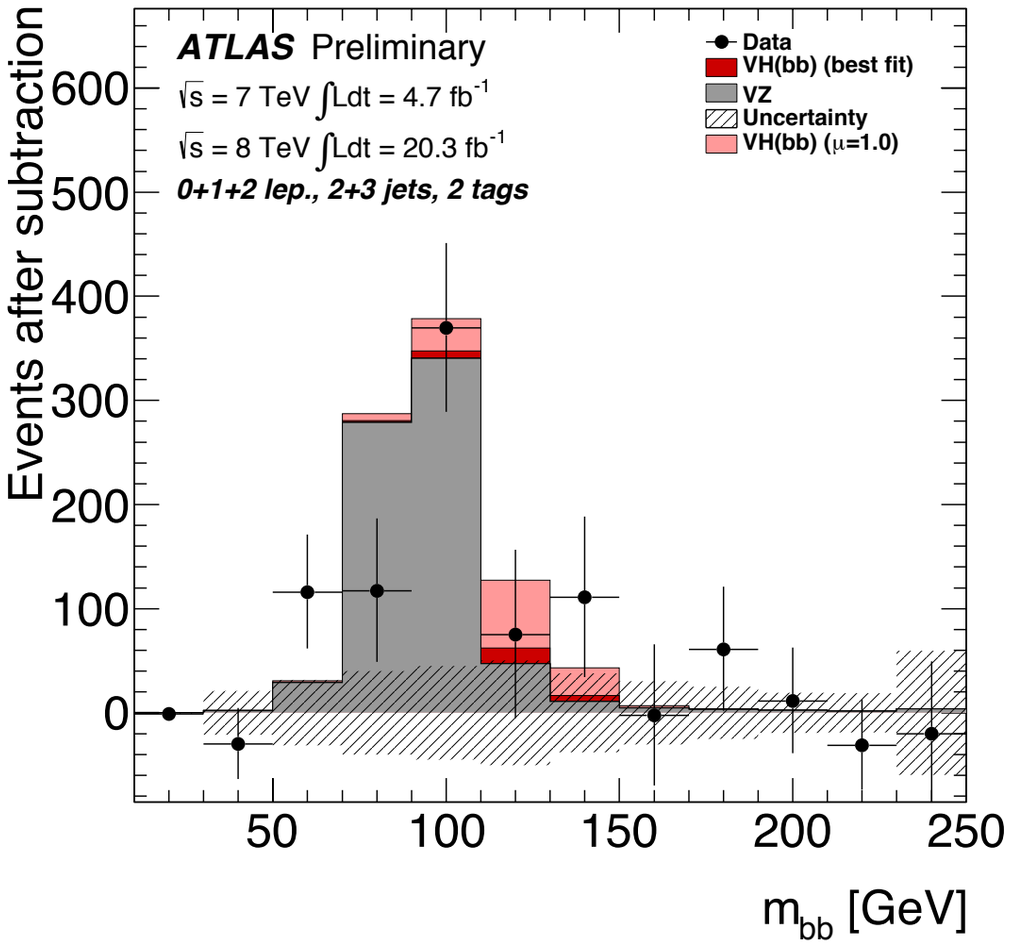


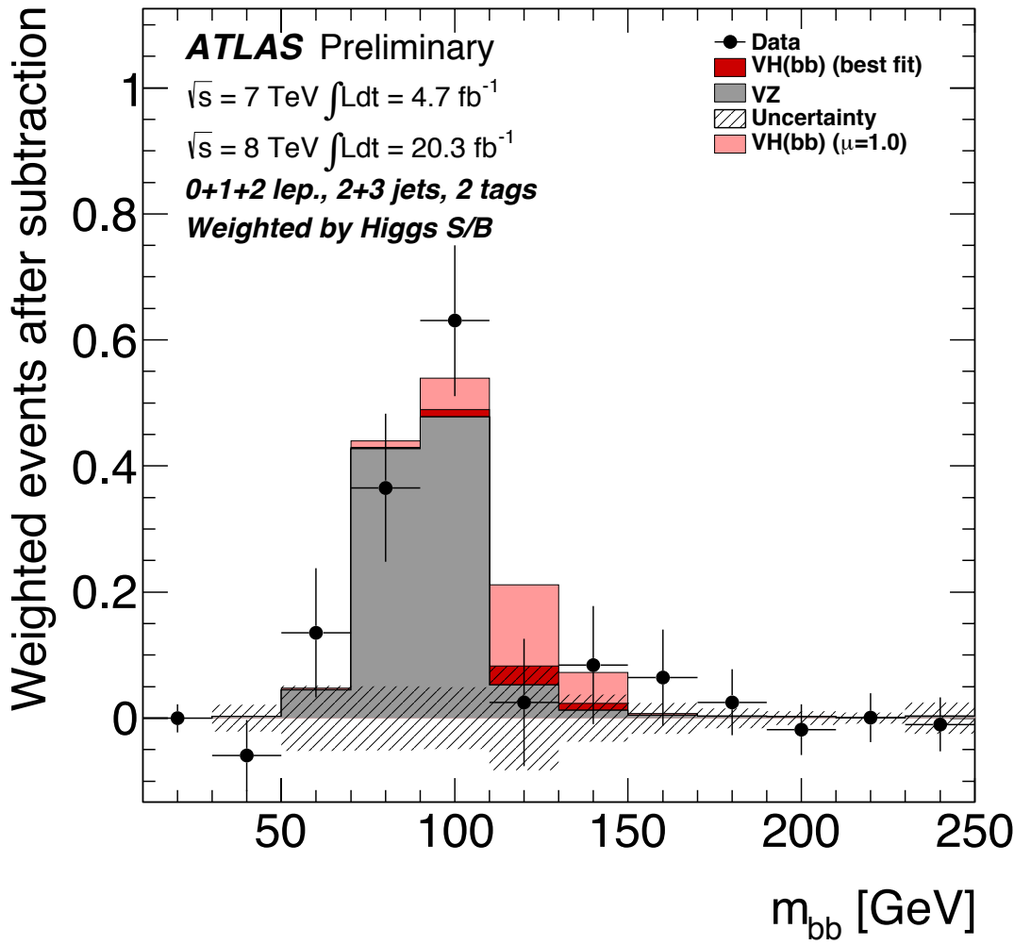
CERN vehicle driving license (V)



http://arxiv.org/pdf/1207.5030.pdf

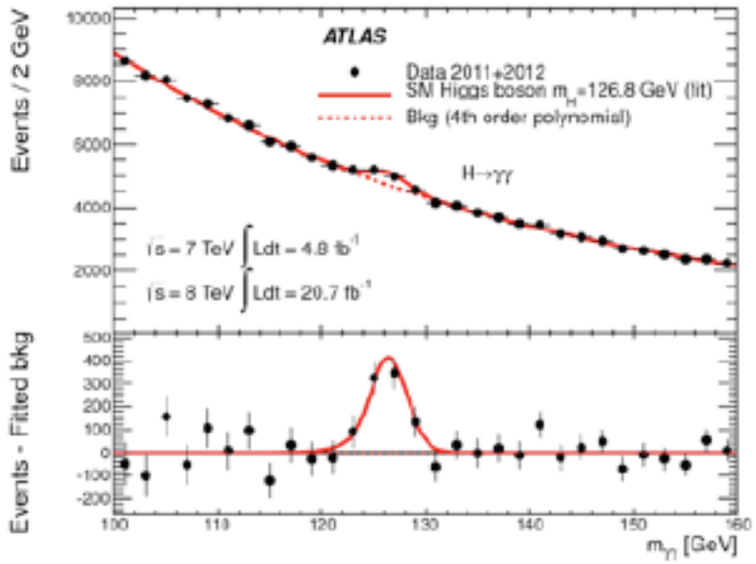
VH (H→bb) results

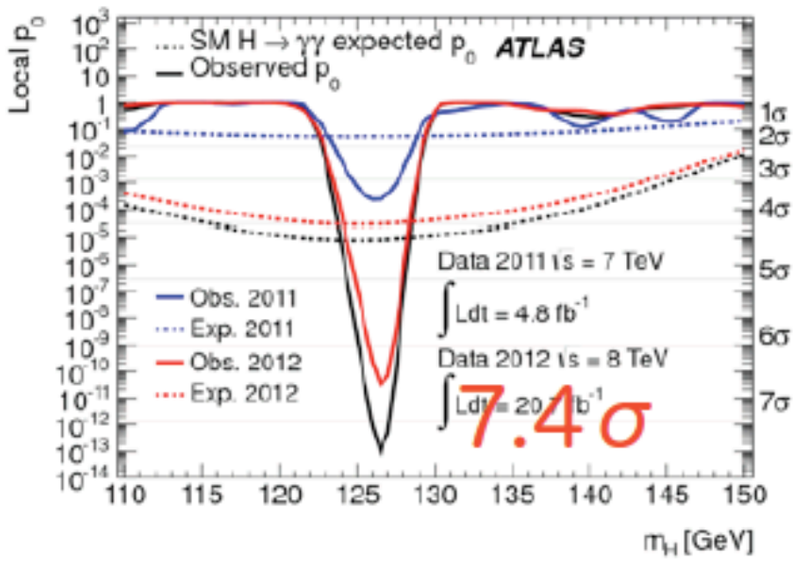




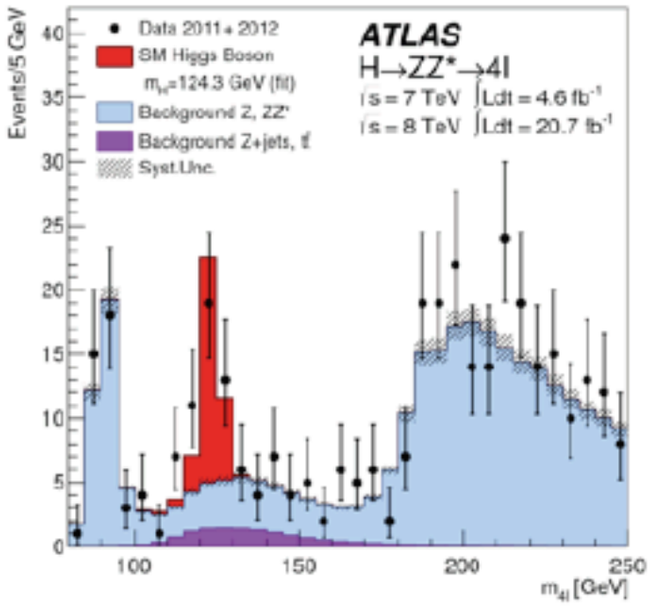
Discovery channels

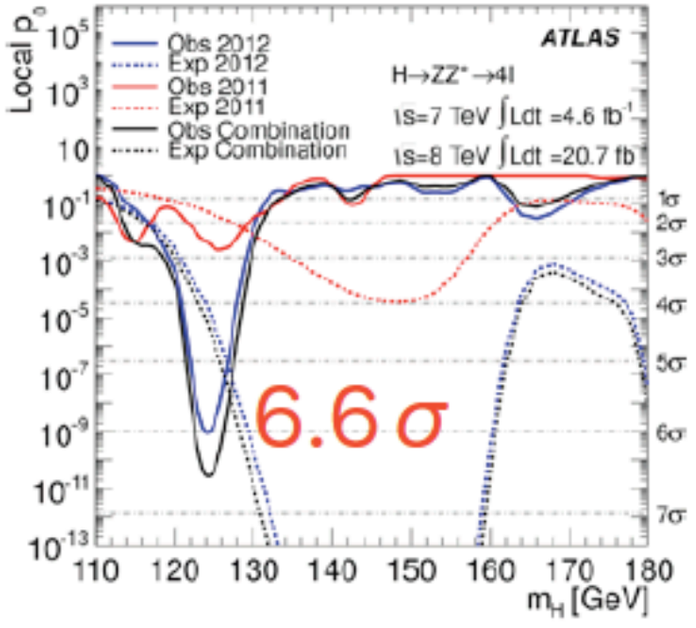
$H \to \gamma\gamma$



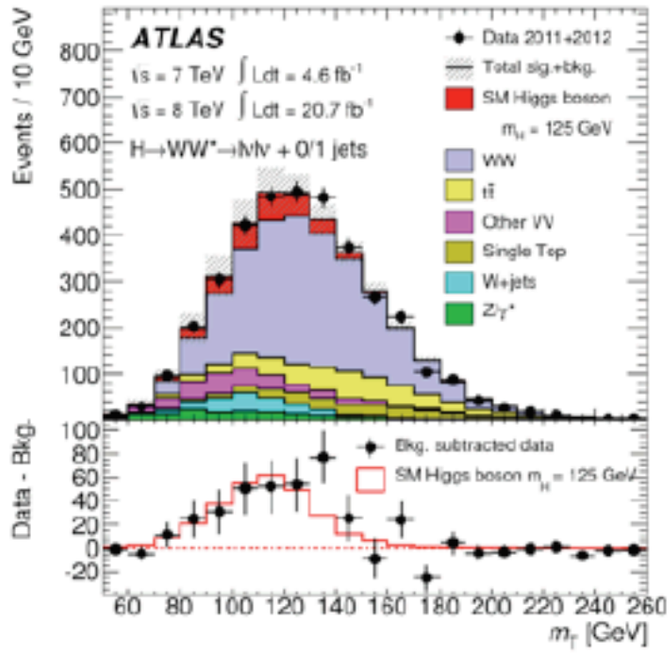


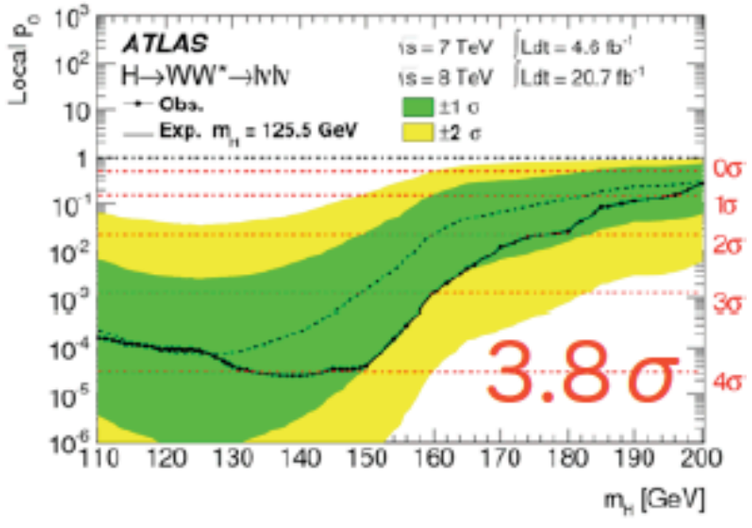
$H \to ZZ$



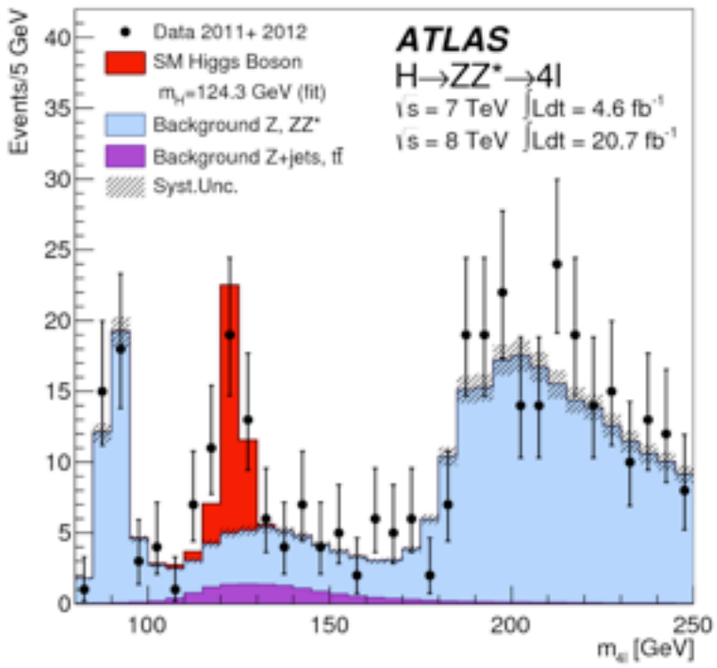


$H \to WW$

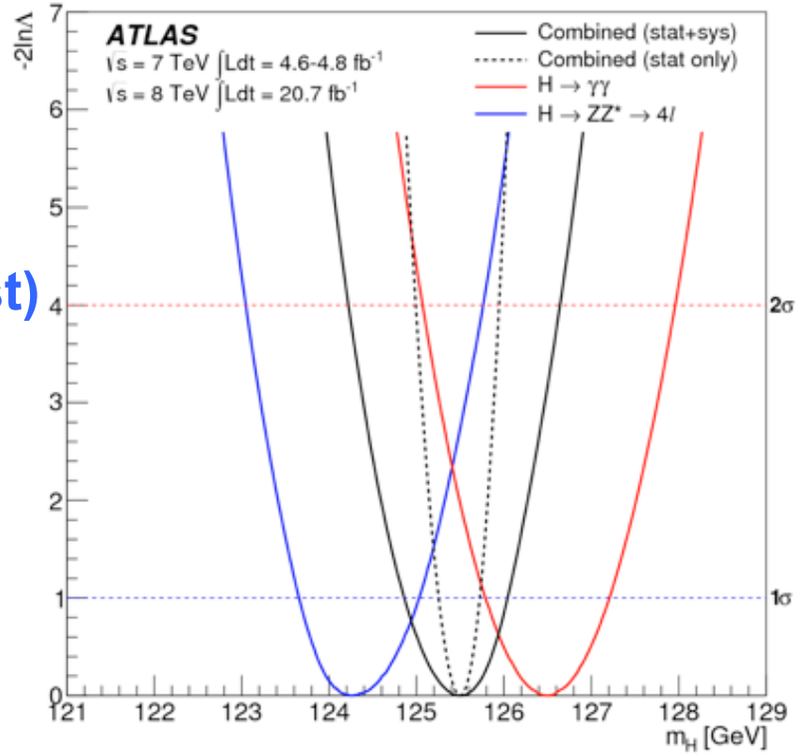


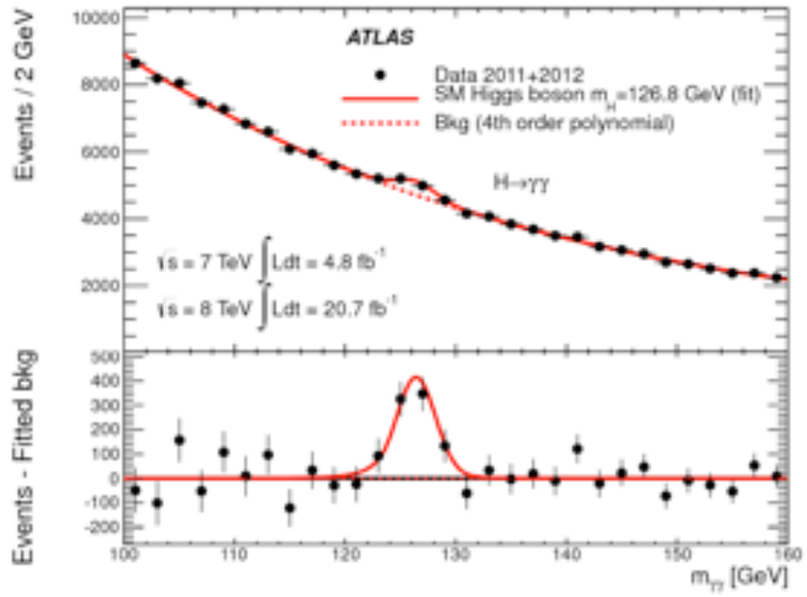


Higgs mass



$m_H = 124.3^{+0.6}_{-0.5}(stat)^{+0.5}_{-0.3}(syst)$ GeV

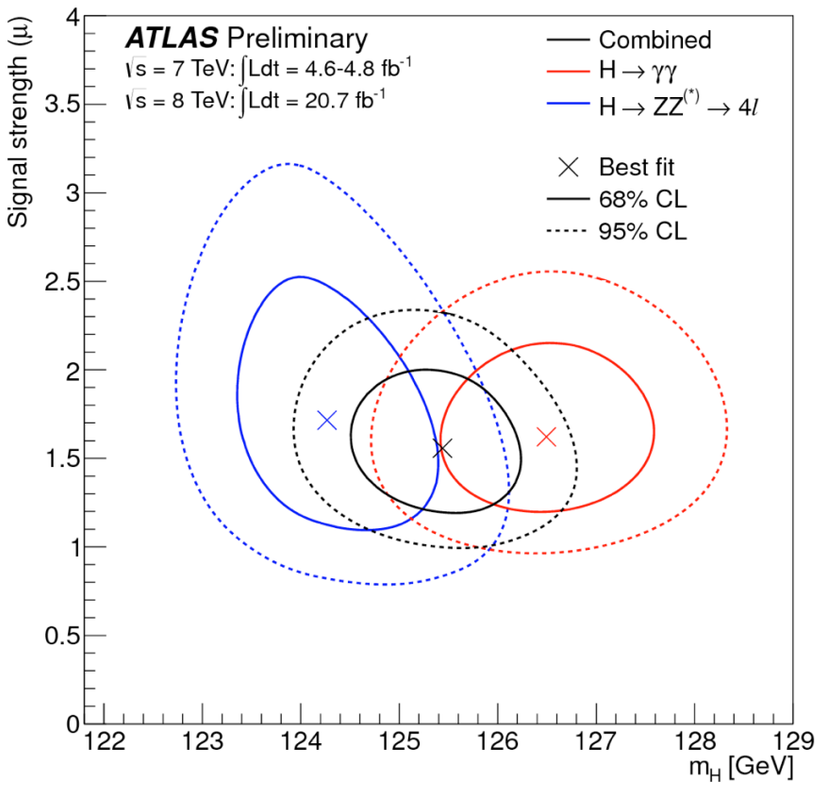




$m_H = 126.8 \pm 0.2(stat) \pm 0.7(syst)$ GeV

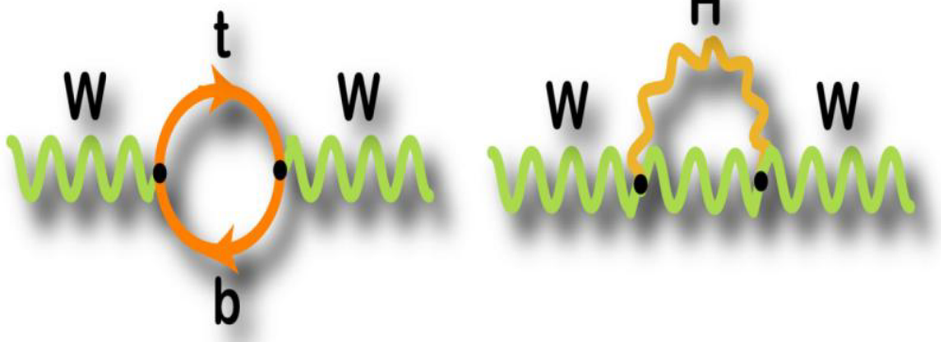
$m_H = 125.5 \pm 0.2(stat)^{+0.5}_{-0.6}(syst)$ GeV

Mass difference about 2.4σ (1.5% prob.)

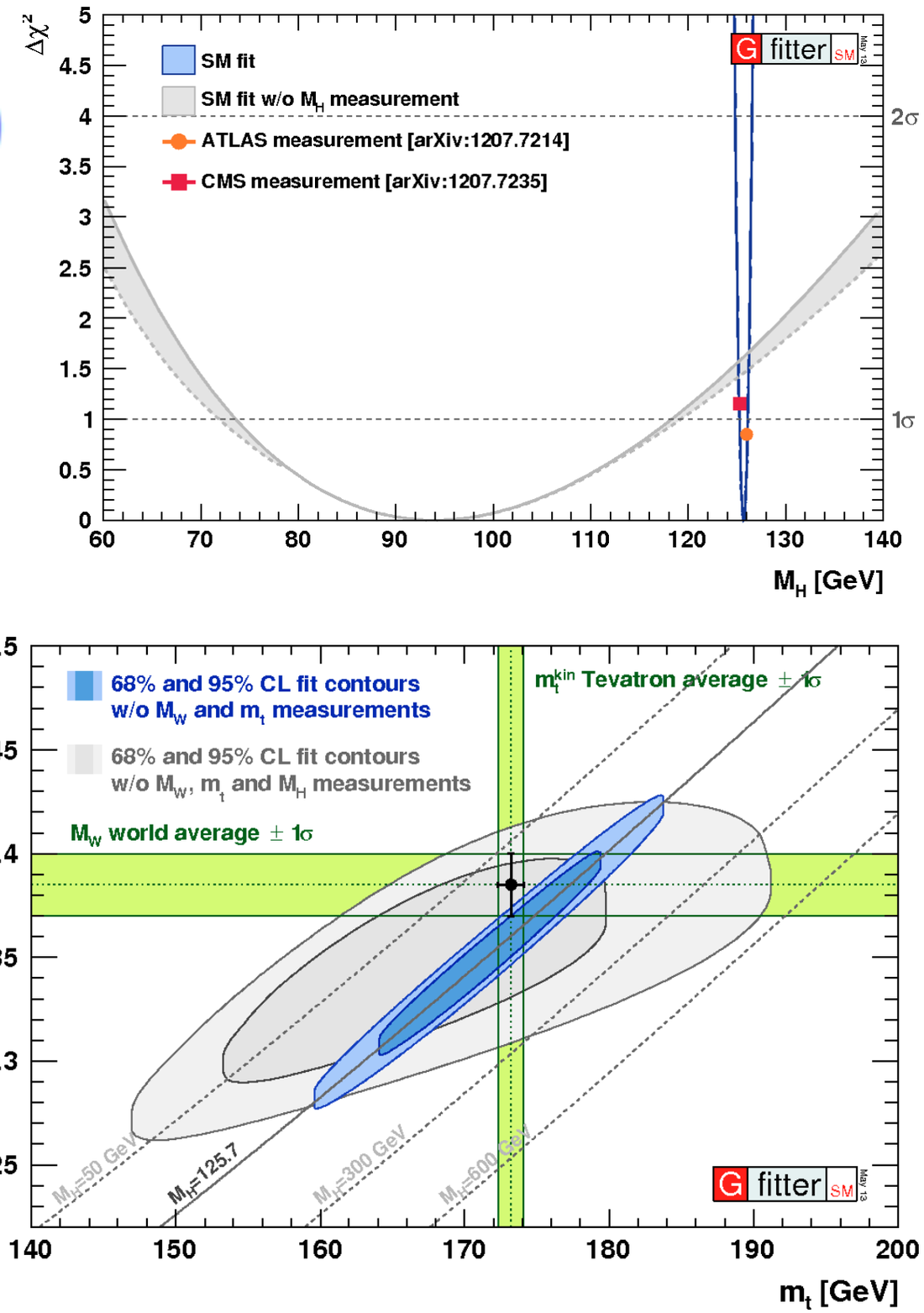


EWK fits vs Higgs

$$m_W^2\left(1-\frac{m_W^2}{m_Z^2}\right)=\frac{\pi\alpha}{\sqrt{2}G_F}(1+\Delta r)$$



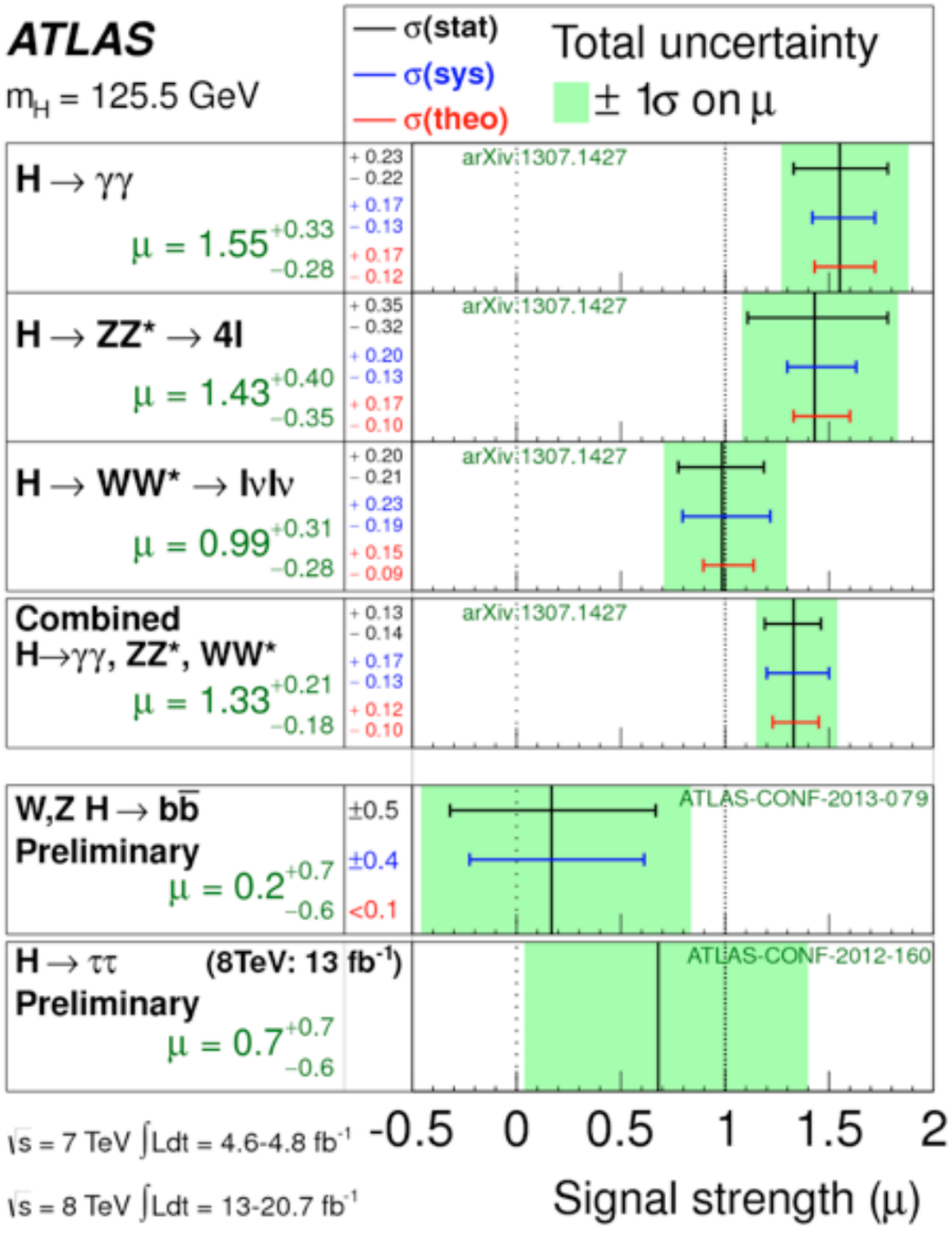
$\Delta r \sim m_{top}^2$ $\Delta r \sim \ln(m_H)$

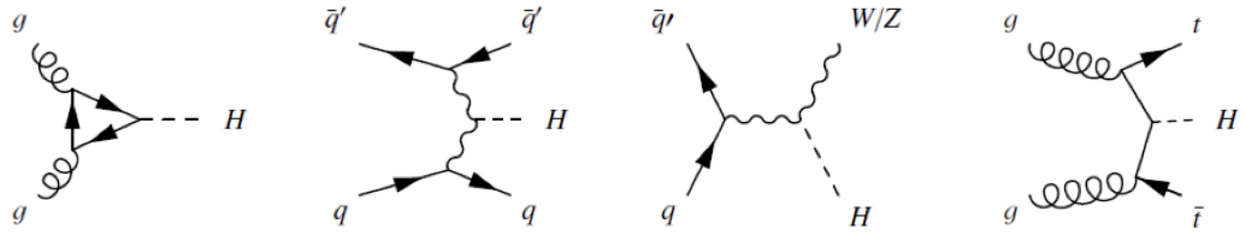


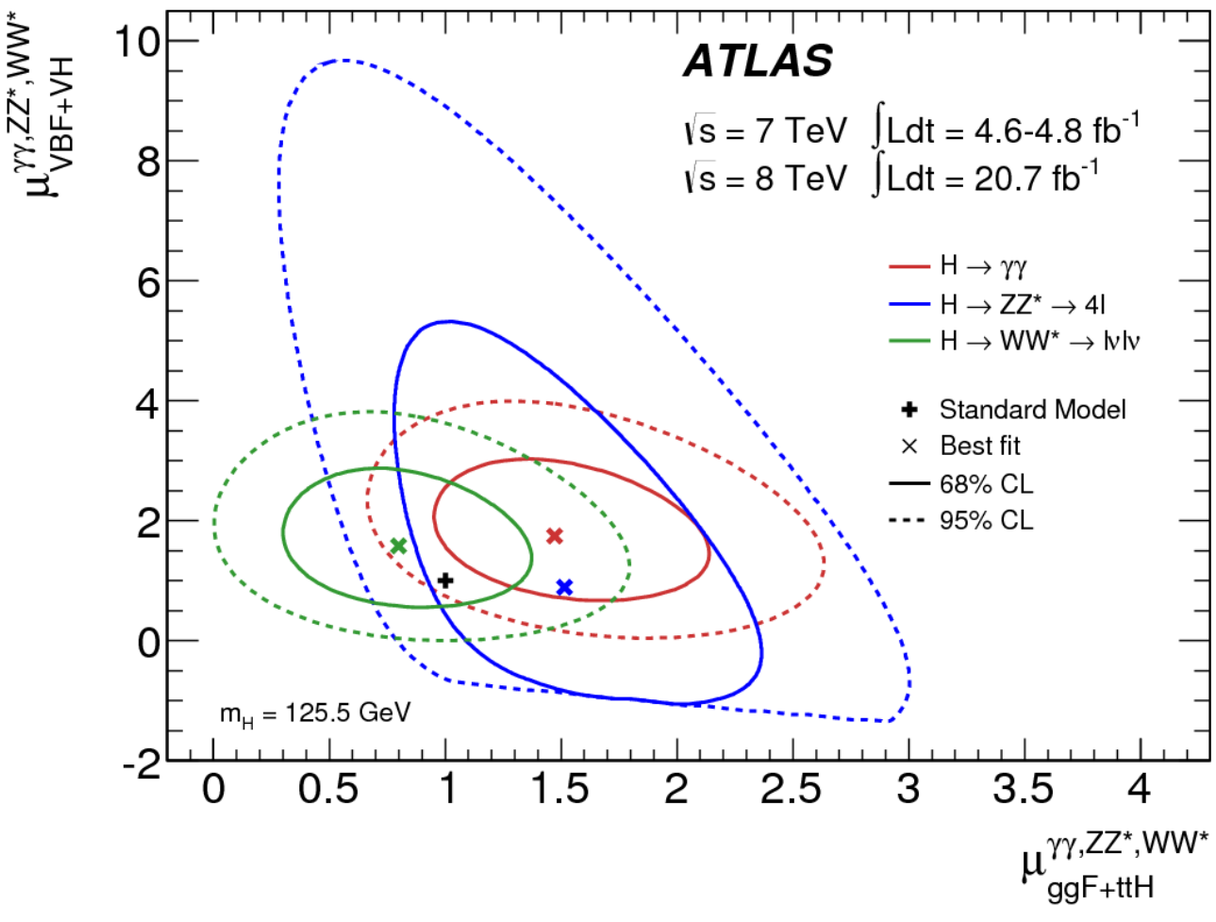
Very remarkable agreement (within 1.3 σ) between direct m_H measurement and the indirect determination via EWK fits

Signal strength

$\mu = (\sigma \times Br)/(\sigma \times Br)_{SM}$







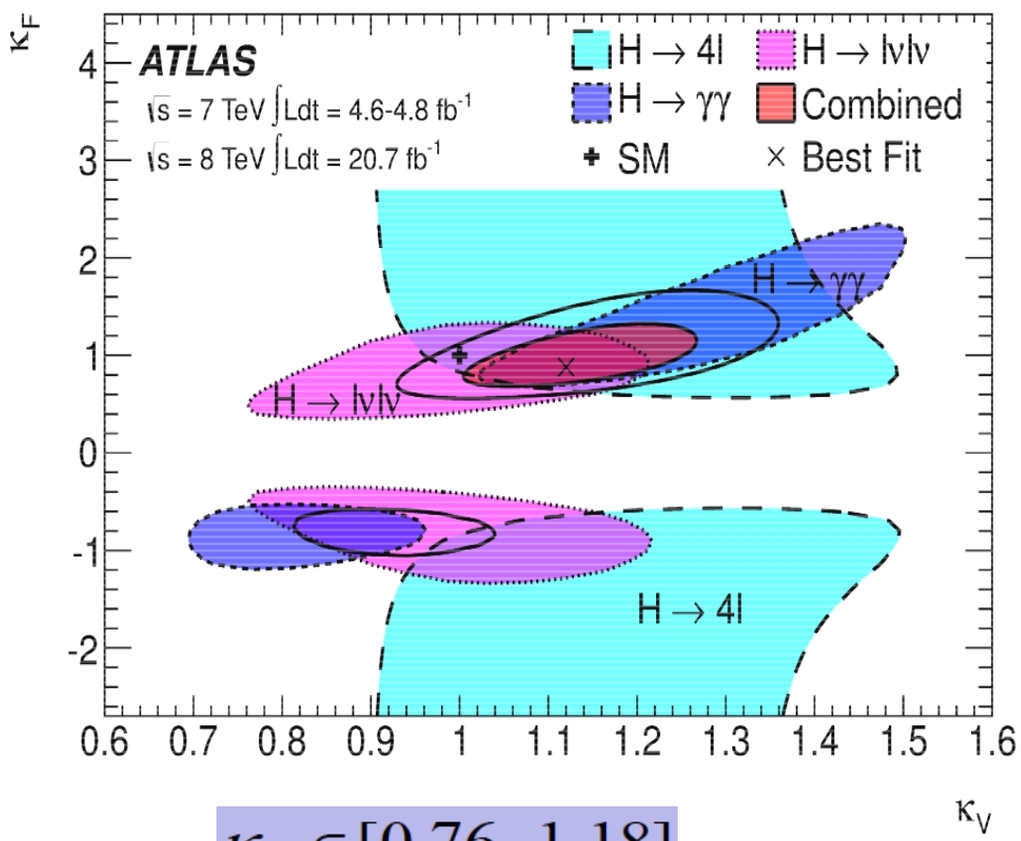
μ = 1.33 ± 0.14(stat) ± 0.15(syst)
(compatible with SM with 7% prob.)

Higgs couplings

κ_F, κ_V : scale factors fermion/boson couplings

κ_g, κ_γ : scale factors gg→H and H→ γγ loops

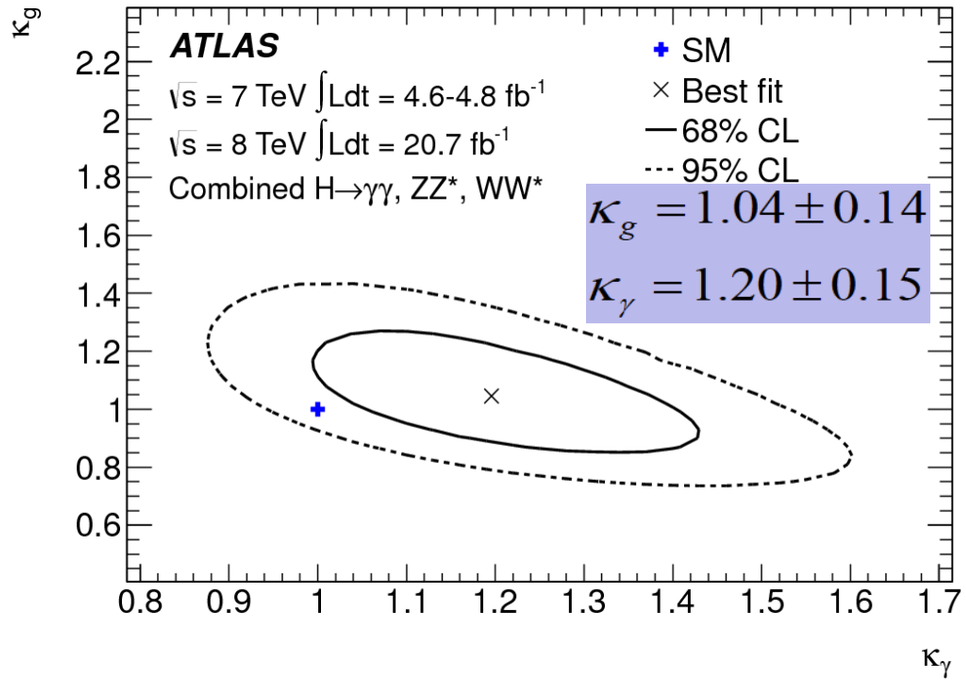
λ_{WZ} : κ_W/κ_Z



$\kappa_F \in [0.76,\ 1.18]$

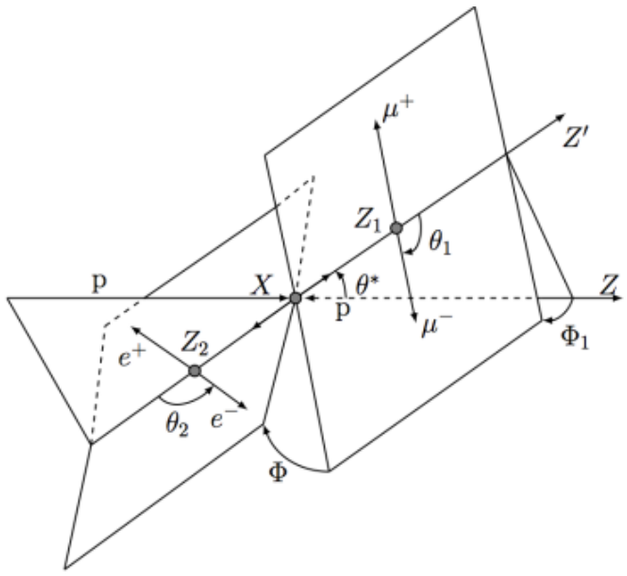
$\kappa_V \in [1.05,\ 1.22]$

@ 68% CL



Consistent with SM predictions

Higgs Spin/Parity ($J^P = 0^+$ vs 0^-)



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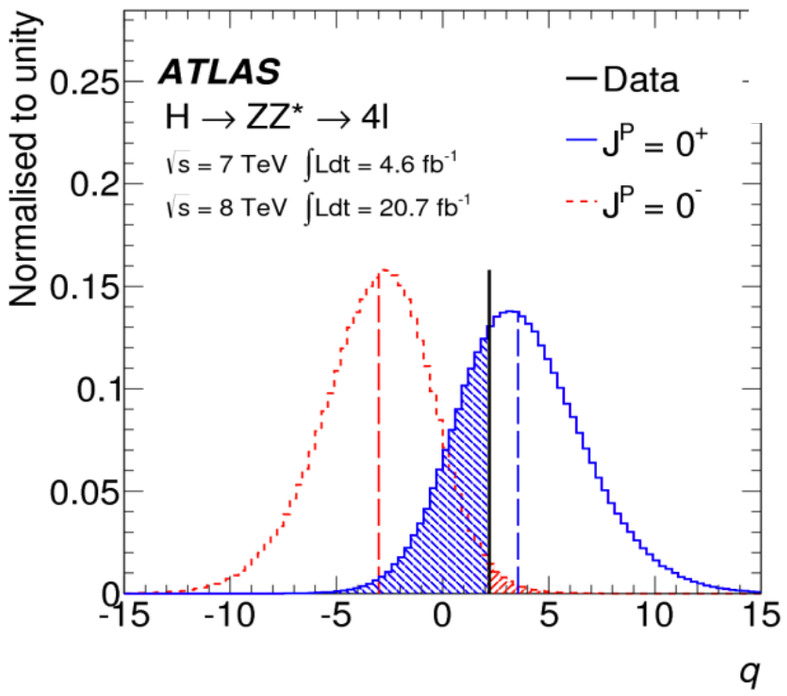

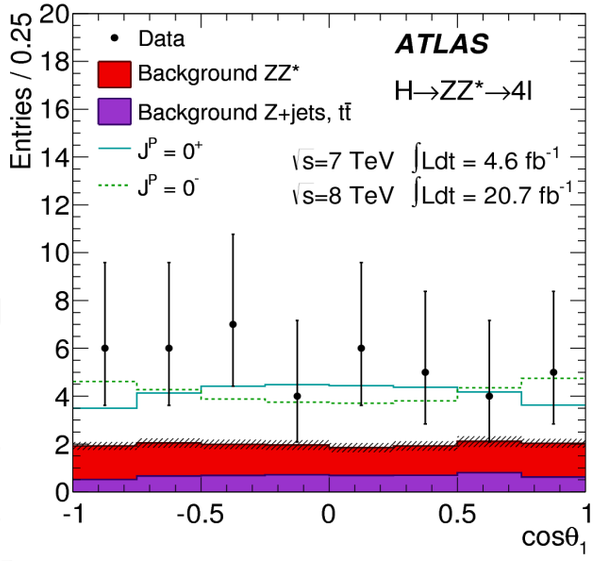

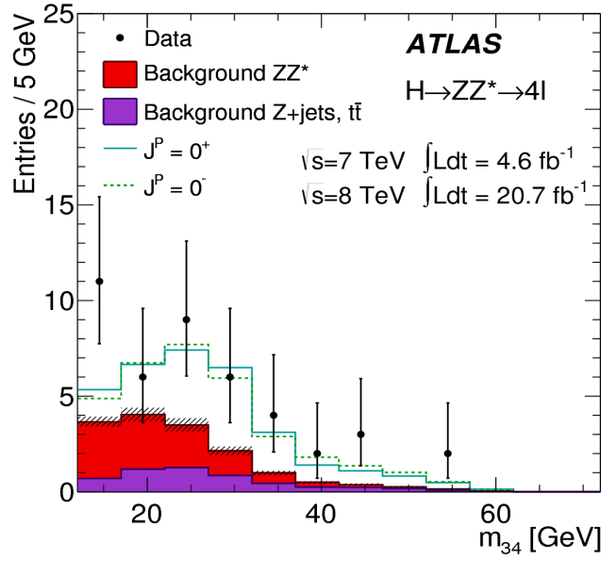

$$q = \log \frac{L(J^p = 0^+)}{L(J^p = 0^-)}$$

Data agree with 0^+ hypothesis
0^- solution excluded at 97.8 % CL

Higgs Spin/Parity

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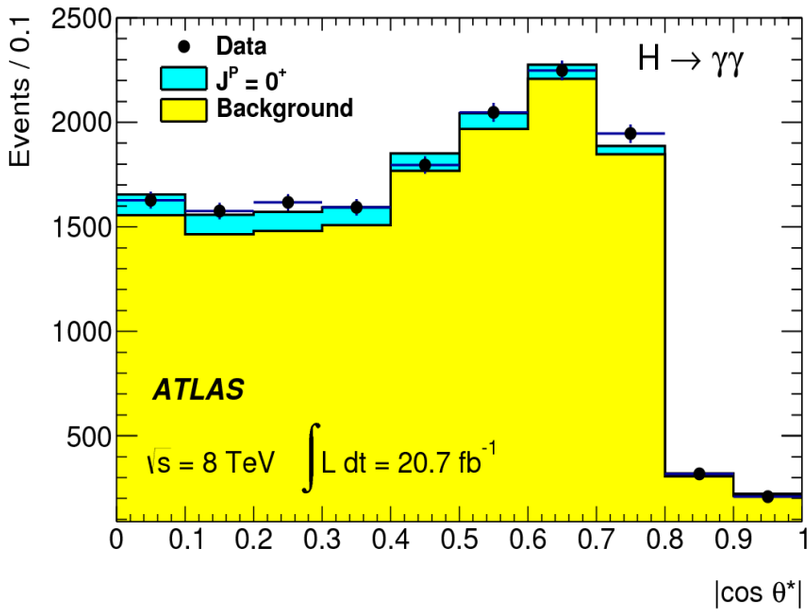
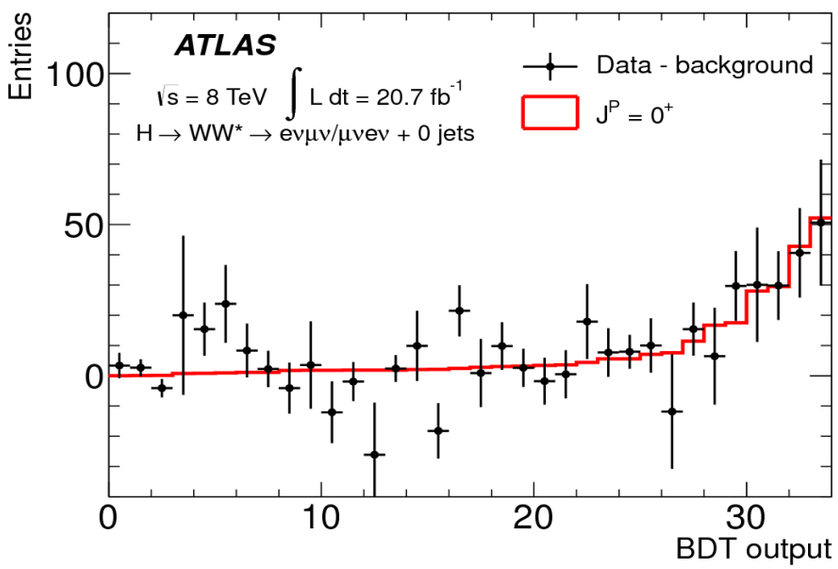
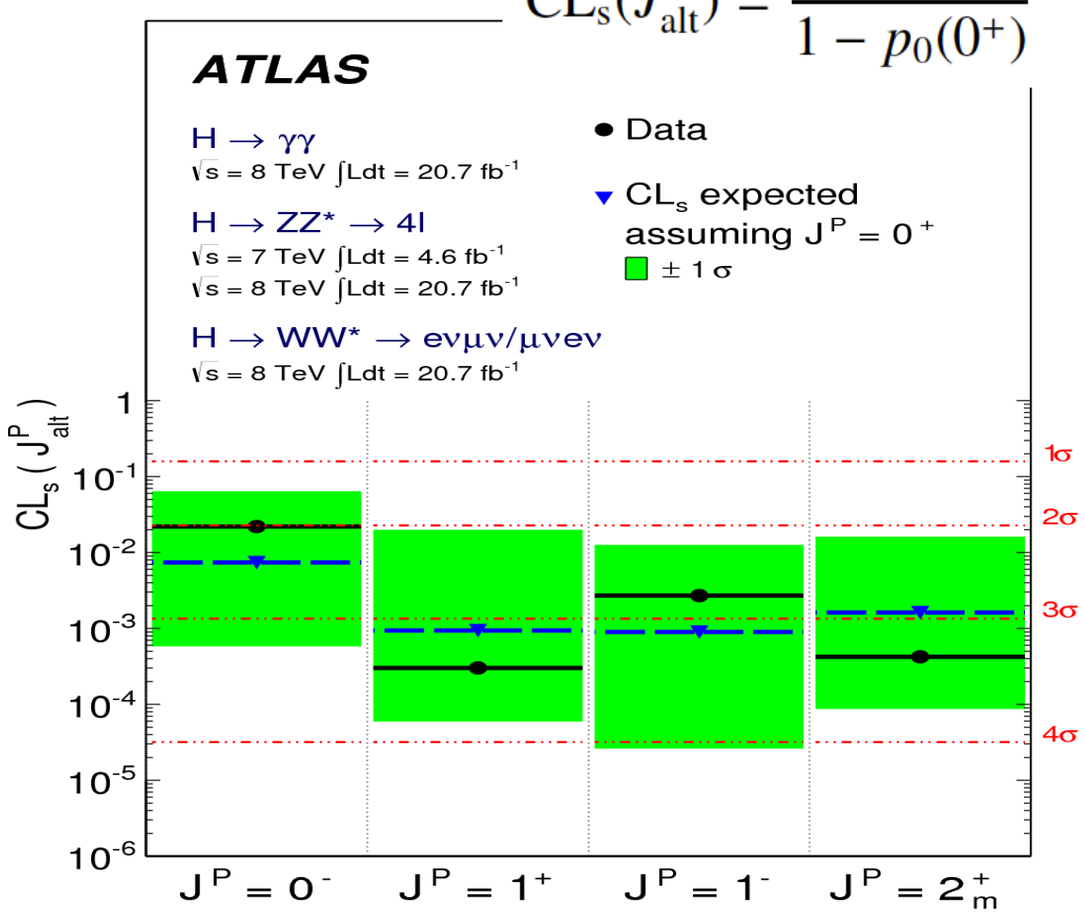




$$CL_s(J^P_{alt}) = \frac{p_0(J^P_{alt})}{1 - p_0(0^+)}$$



$J^P = 1^+$ and 1^- rejected at 99.7% CL
$J^P = 2^+$ rejected at 99.9% CL

→ Evidence for $J^P = 0^+$

H -> ττ

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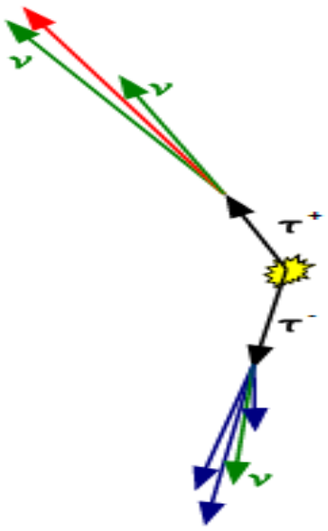
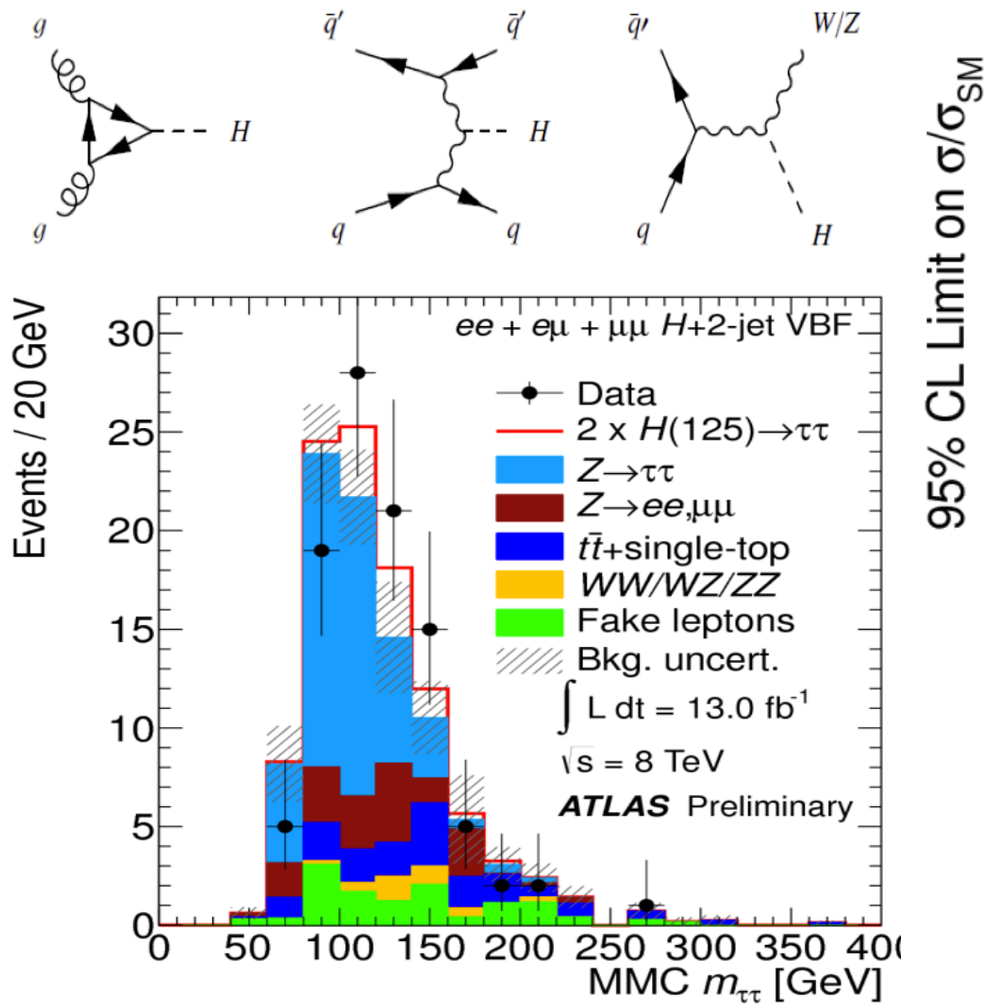
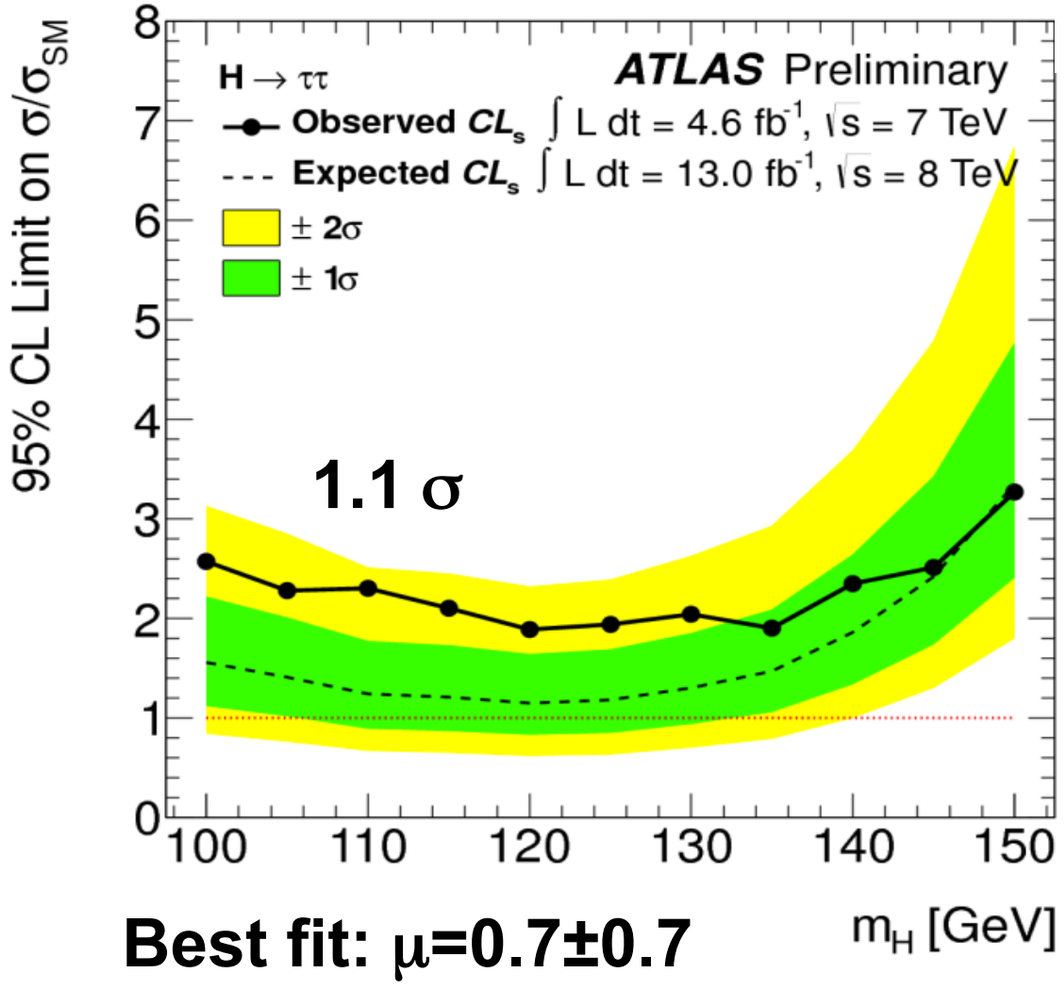
Analysis in mutiple channels with +0/1/2-jets in the final state

2-jet channels optimized for VBF and VH

Considering lepton-lepton, lepton-hadron and hadron-hadron tau decay channels



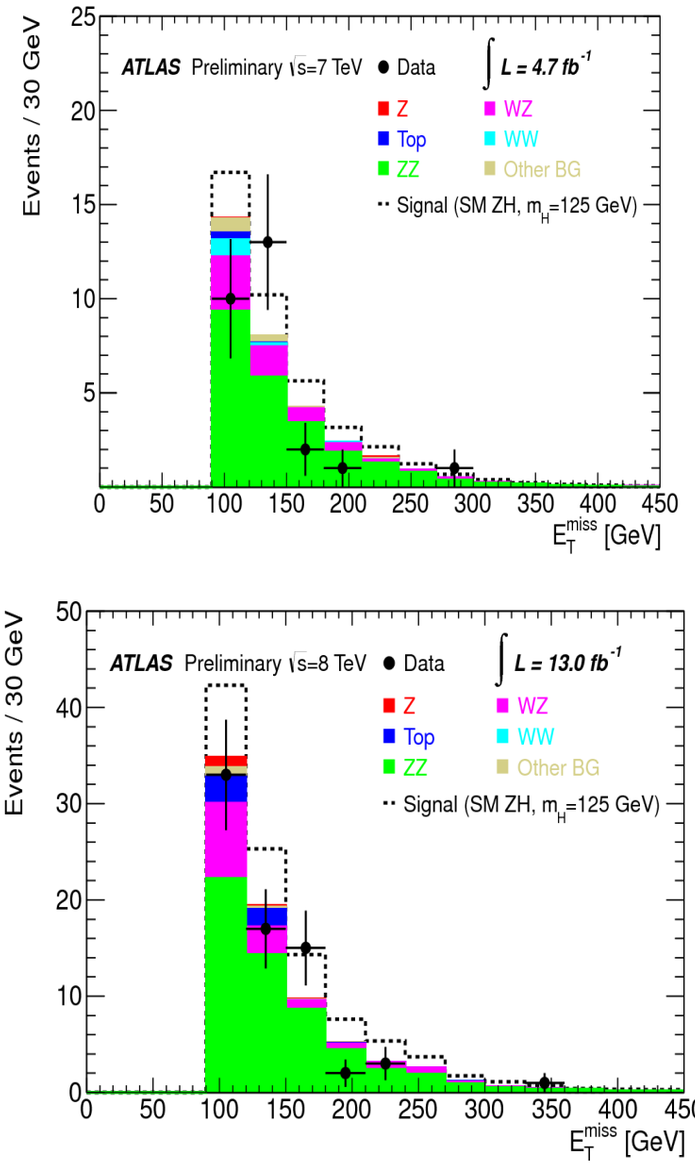




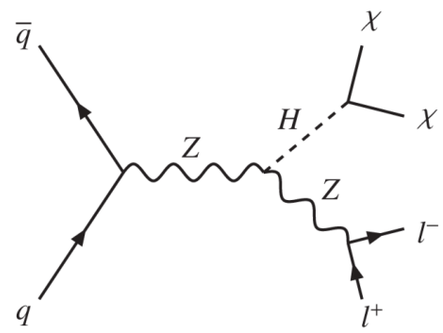
Best fit: μ=0.7±0.7

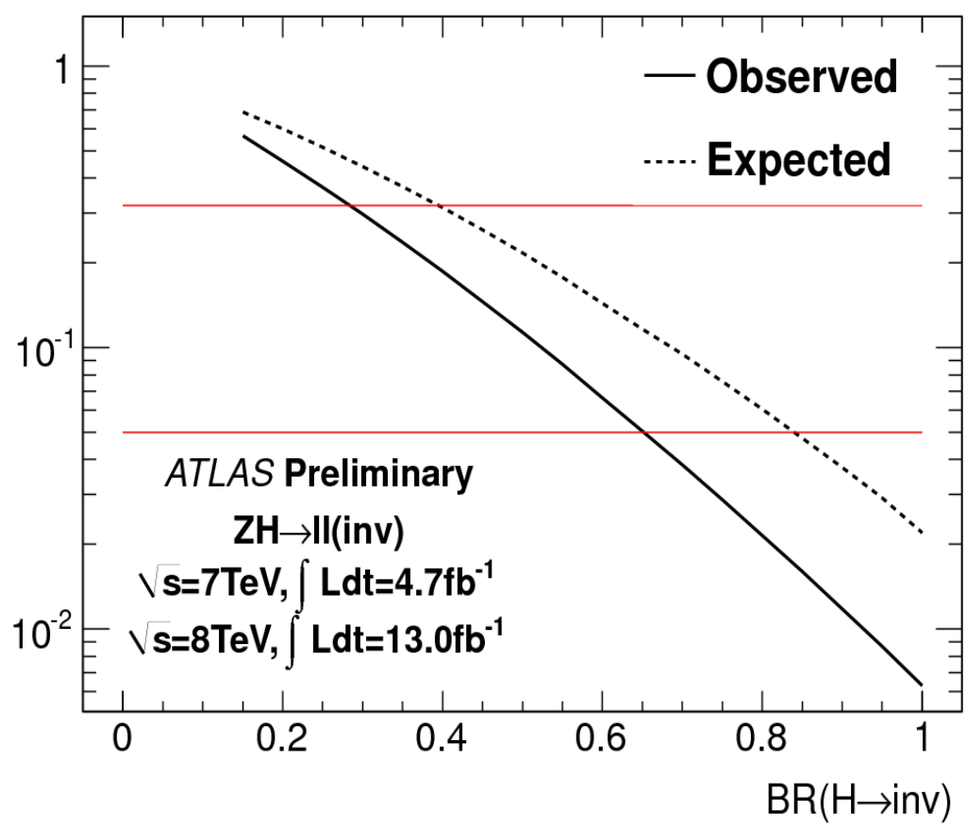
H -> $\chi\chi$

ATLAS-CONF-2013-011



2l + E_T^{miss}





Br (H → invisible) < 65% at 95% CL