Search for the Standard Model Higgs boson decaying to a b-quark pair with the ATLAS Detector

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on behalf of the **ATLAS** Collaboration

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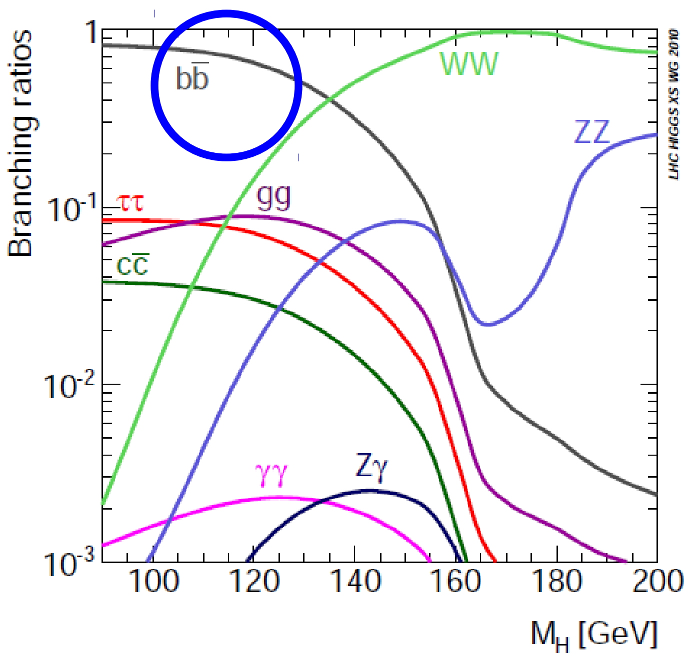
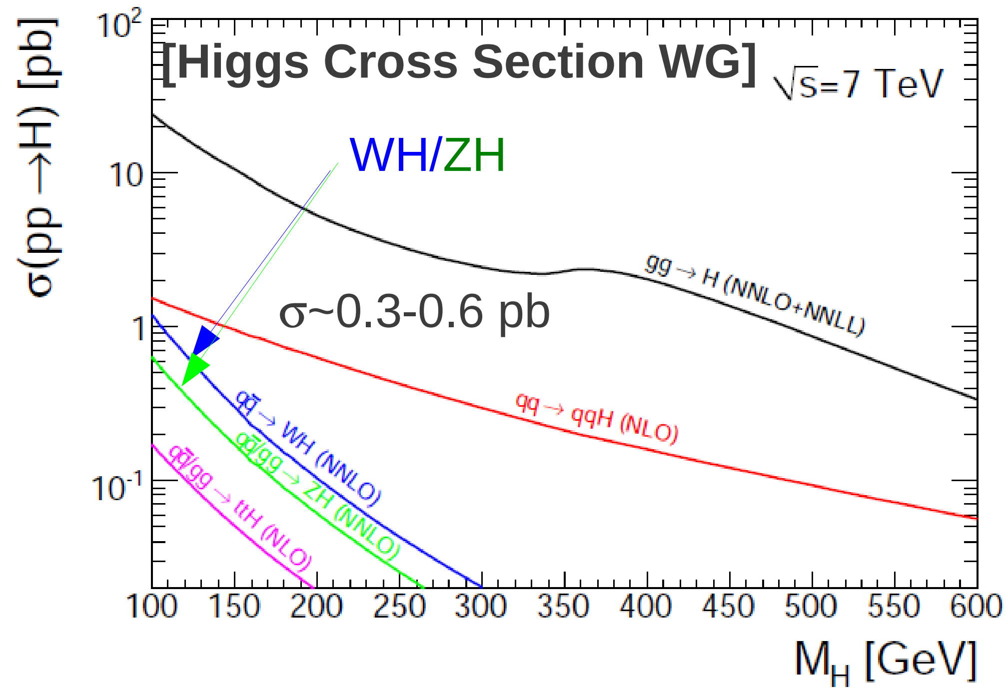
ICHEP Conference - Melbourne

Higgs boson searches with b-quark jets



- The observation of H → bb is an important step for establishing a Standard Model Higgs boson.
- Challenging, despite the high *BR* for low Higgs boson masses.

√s = 7 TeV

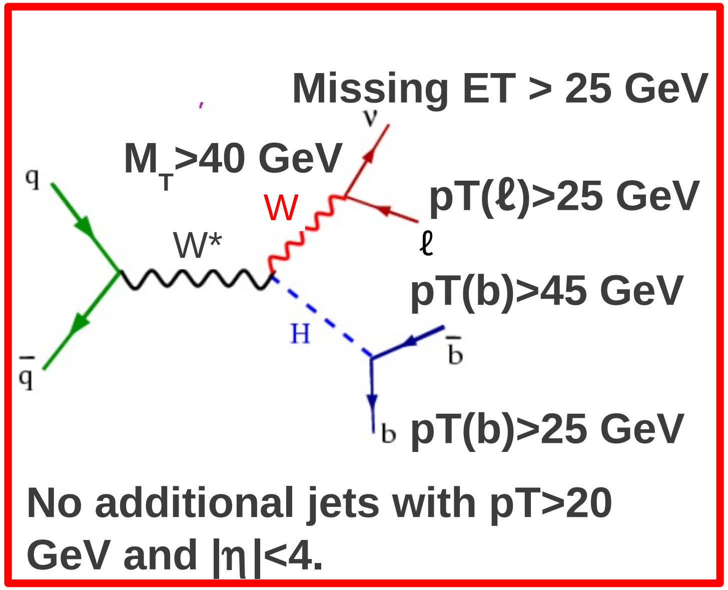


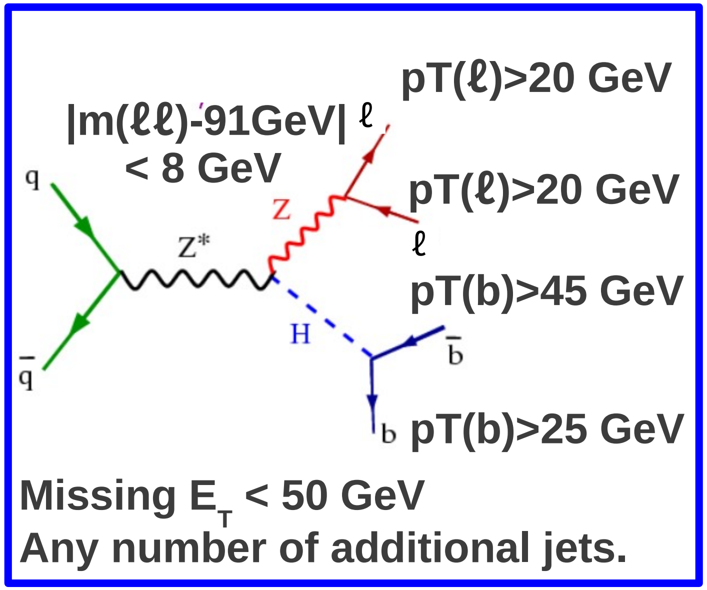
- Exploit leptonic decay modes (ll, lν, νν) of W/Z bosons produced in association with the Higgs boson
- Identify b jets and look for a broad peak in the bb-jet invariant mass distribution (σ ~ 15 GeV).

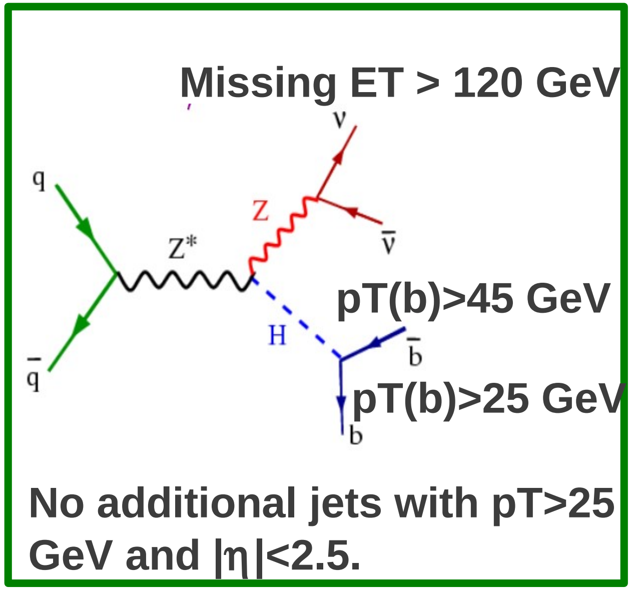
Selection strategy

- Three channels considered: $WH \rightarrow \ell\nu b\bar{b}$ $ZH \rightarrow \ell^+\ell^- b\bar{b}$ $ZH \rightarrow \nu\bar{\nu} b\bar{b}$
- Analysis based on 4.6-4.7 fb^{-1} of 2011 data collected by ATLAS at $\sqrt{s}$ = 7 TeV
- Main selection cuts:

+ contributions from WH

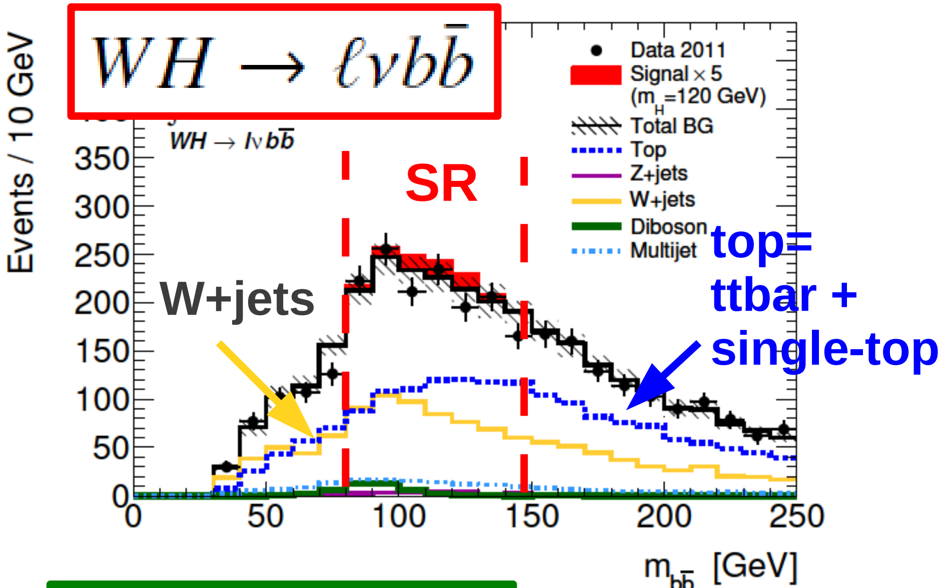


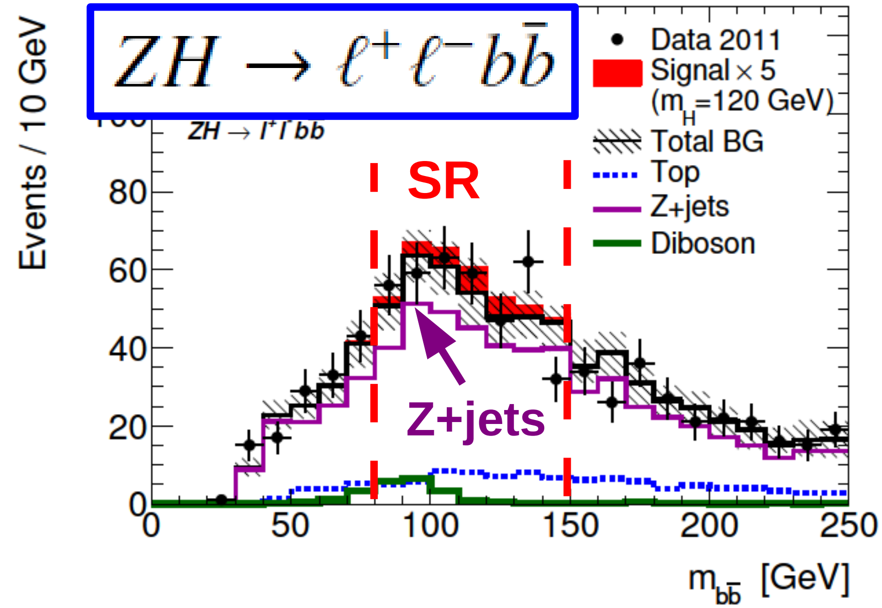


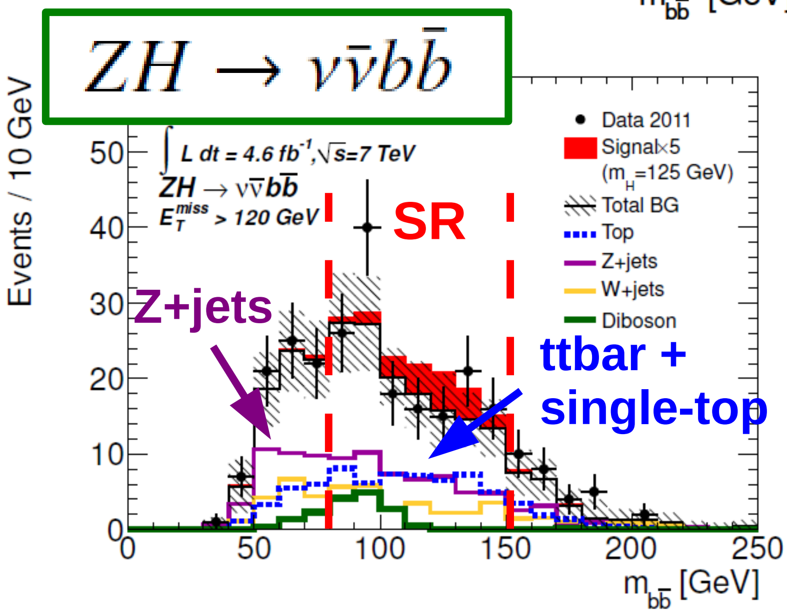


- Anti-Kt jets with R=0.4 are reconstructed from calorimeter energy deposits.
- Pile-up jets are suppressed by requiring more of 75% of the summed momenta of tracks matched to the jet to be associated to the primary event vertex.

Main backgrounds



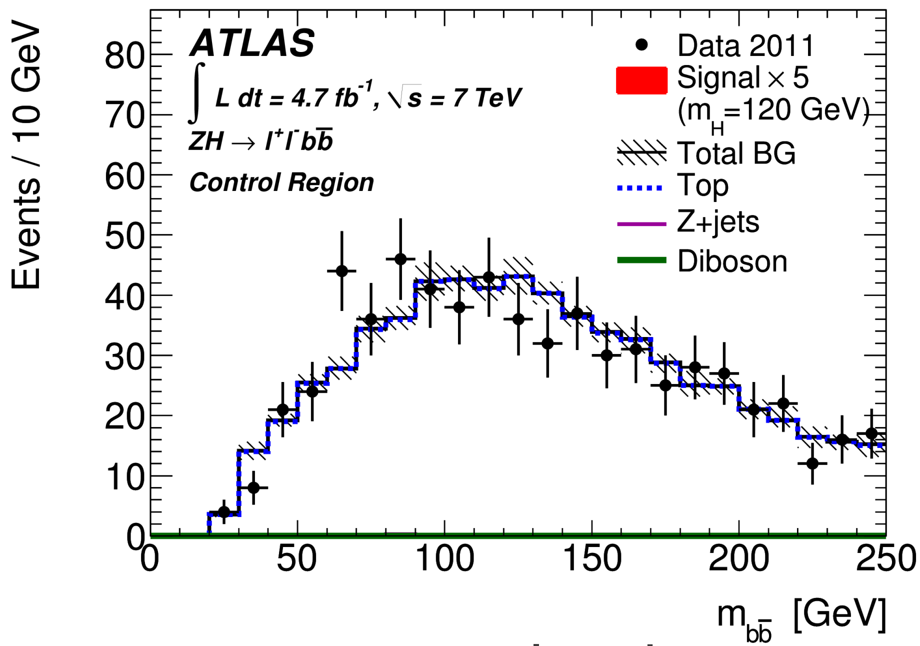


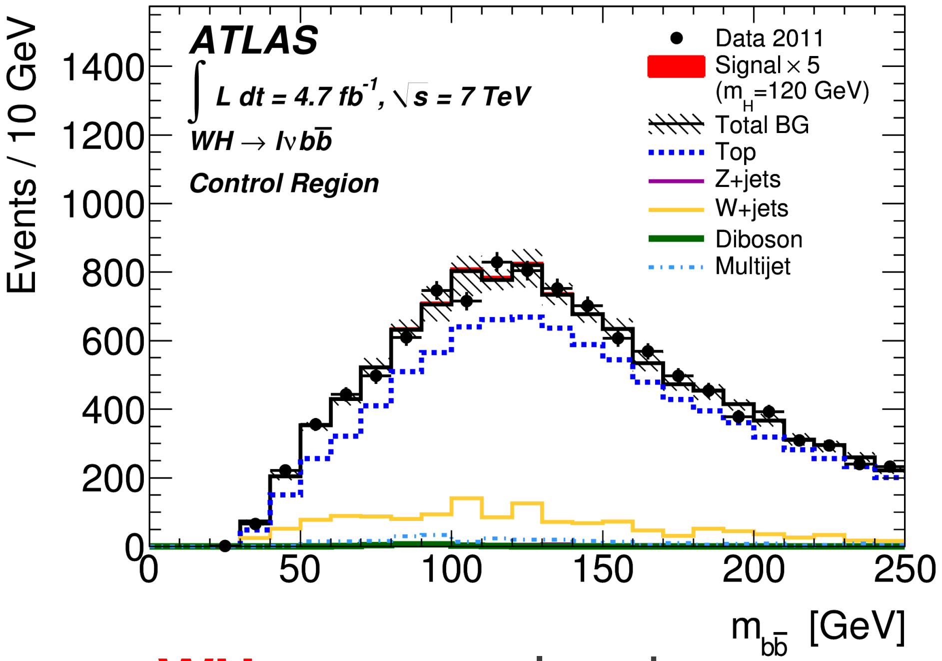


\+ **resonant background** from diboson

- M(bb) shape from MC, normalization of main backgrounds from data (excluding **SR**)
- $WH \rightarrow \ell\nu b\bar{b}$: Top and W+jet scale factors from m(bb) sidebands + WH top control region
- $ZH \rightarrow \ell^+\ell^- b\bar{b}$: Top and Z+jet scale factors from m(bb) sidebands + ZH top control region
- $ZH \rightarrow \nu\bar{\nu}b\bar{b}$: take scale factors from other channels, after cross-checking in dedicated control regions.

Top background control regions



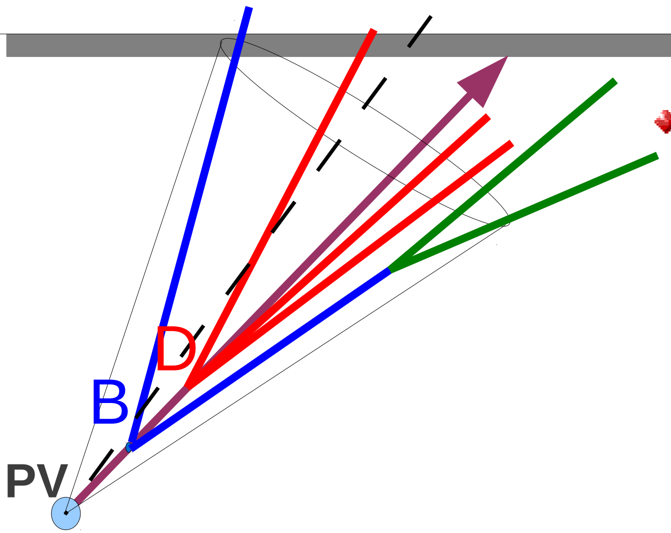


- **ZH** top control region:
  - |m(ℓℓ)-91GeV|>15 GeV
  - ETmiss > 50 GeV

- **WH** top control region:
  - Require 3 instead of 2 jets in the events

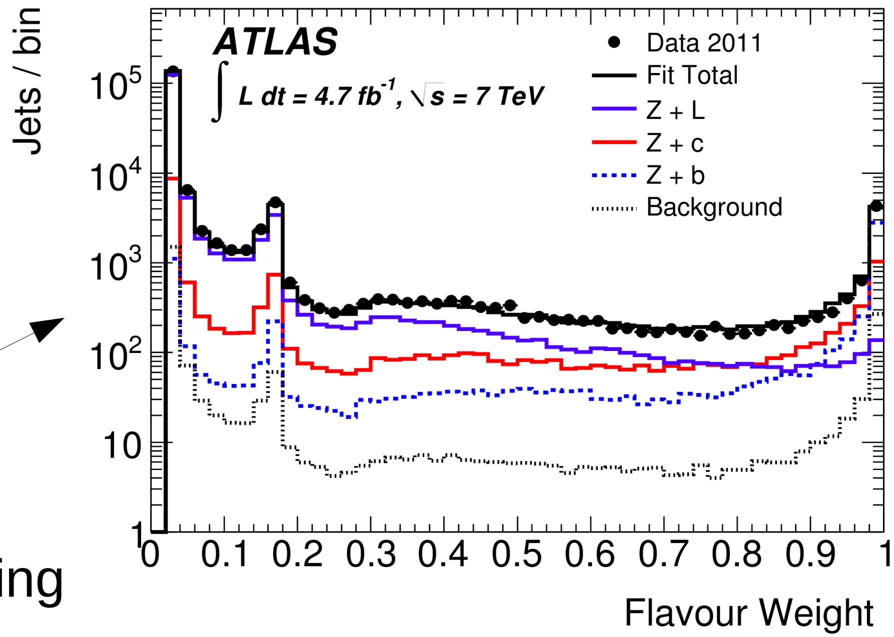
Very good agreement in m(bb) shape after simultanous fit to top and W+jet backgound normalizations. Normalization for W+jet background in 3 jet bin determined independently from W+jet in 2 jet bin.

W/Z+jet backgrounds



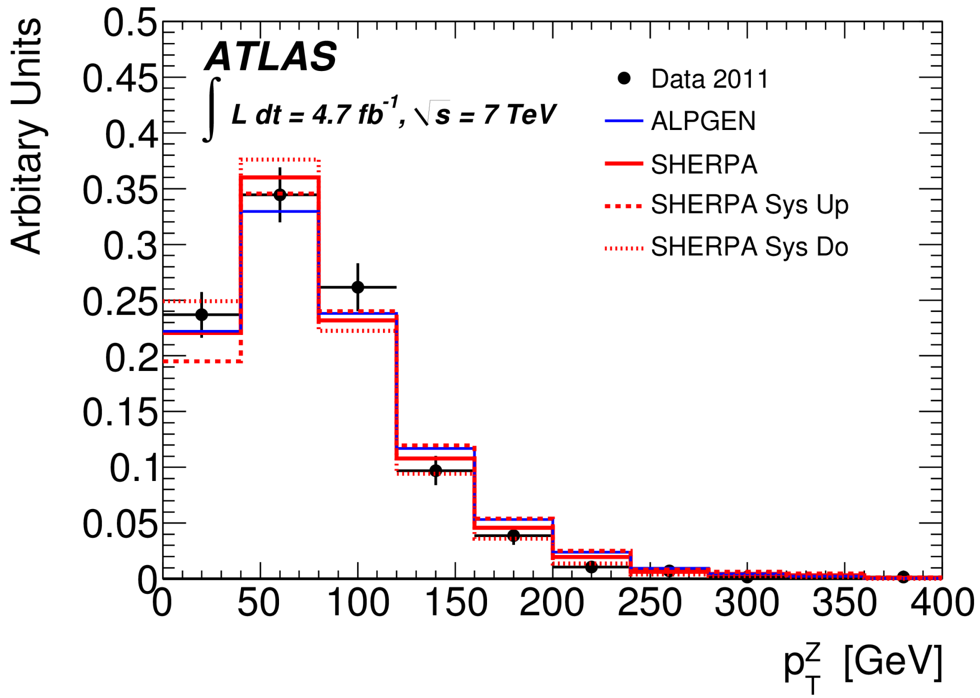
- **b-tagging algorithm:** to suppress W/Z+light/c-jet background, Neural Network combines most advanced algorithms (3d impact parameter + inclusive vertex finder dedicated PV→b→c decay chain fit)
  → **ε(light)~0.6%**, **ε(c-jet)~20%**, **ε(b-jet)~70%**.

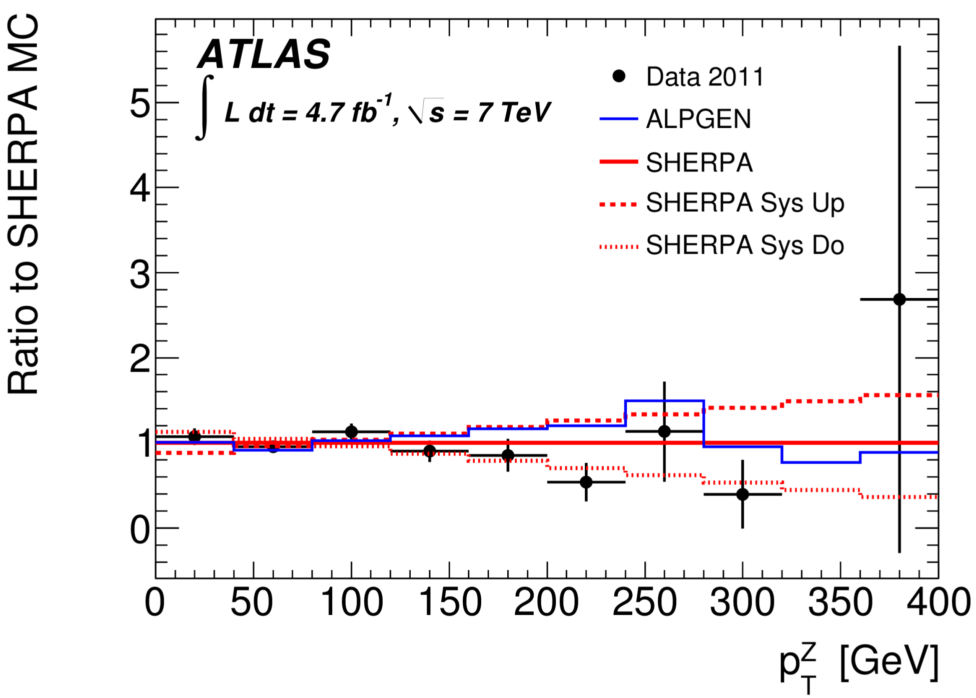
- Determine separate **W/Z+b**, **W/Z+c** and **W/Z+light-jet fractions** from data in 2-jet events requiring m(jet-jet) < 80 GeV:
  - in events with one b-tagged jet, based on the b weight of the second jet.
  - in events with no b-tagged jets, based on the b weight of the first two jets.
- Flavour fractions determined before proceeding with nominal fit.



W/Z+jet backgrounds (II)

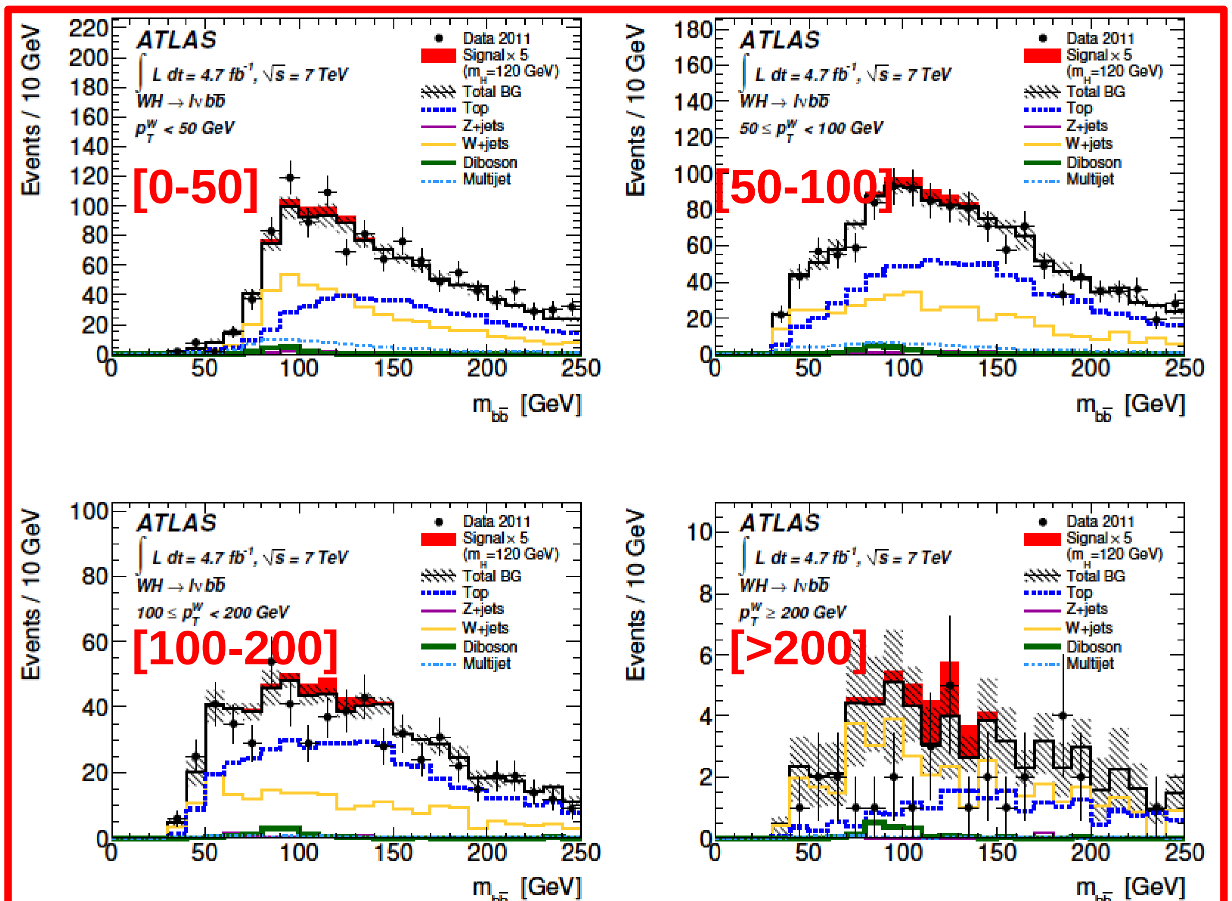
- A possible mismodeling of the m(bb) and p_T(W/Z) “shapes” considered as a systematic uncertainty:
  - for W+bb, considering differences between various models (Alpgen+Herwig, Powheg+Pythia or Herwig, aMC@NLO+Herwig)
  - for Z+bb, from difference between data and MC predictions in the m(bb) sidebands





Analysis optimization

- To exploit the better S/B of the high p_T phase space region, all three channels sub-divided into intervals of p_T(W) or p_T(Z) **[GeV]**:
  - $WH \to \ell\nu b\bar{b}$ $ZH \to \ell^+\ell^- b\bar{b}$:4 pT(W/Z) bins [0-50,50-100,100-200,>200]
  - $ZH \to \nu\bar{\nu} b\bar{b}$: 3 pT(Z) bins [120-160,160-200,>200]



- Further topological cuts in ZH → ννbb on DR(bb),Δϕ(MET,bb).
- S/B enhanced from ~1% to ~15% in the highest p_T bin.
- This increases the number of "effective" channels from 3 to 11.
- Proper estimation of systematic uncertainty on p_T(W) or p_T(Z) modelling becomes crucial.

Yields and leading background uncertainties

Bin	$ZH \rightarrow \ell^+\ell^- bb$ p_T^Z [GeV]				$WH \rightarrow \ell\nu bb$ p_T^W [GeV]				$ZH \rightarrow \nu\bar{\nu}bb$ E_T^{miss} [GeV]		
	0-50	50-100	100-200	>200	0-50	50-100	100-200	>200	120-160	160-200	>200
Number of events for $80 < m_{b\bar{b}} < 150$ [GeV]											
Signal	1.3 ± 0.1	1.8 ± 0.2	1.6 ± 0.2	0.4 ± 0.1	5.0 ± 0.6	5.1 ± 0.6	3.7 ± 0.4	1.2 ± 0.2	2.0 ± 0.2	1.2 ± 0.1	1.5 ± 0.2
Total Bkg	148 ± 10	150 ± 6	67 ± 4	6.9 ± 1.2	596 ± 23	598 ± 16	302 ± 10	27 ± 5	85 ± 8	32 ± 3	20 ± 3
Data	141	163	61	13	614	588	271	15	105	22	25
Components of the Background Relative Systematic Uncertainties [%]											
Theory	5.2	1.3	4.7	14.9	2.2	0.3	1.6	14.8	2.9	4.0	7.7

- **Theory uncertainty** : **~1-15 %**
  - One of the leading uncertainties
  - Mainly from m(bb) and pT(W/Z) modelling in W/Z+heavy flavour.

Leading background uncertainties

Bin	$ZH \to \ell^+\ell^- bb$ p_T^Z [GeV] 0-50	50-100	100-200	>200	$WH \to \ell\nu bb$ p_T^W [GeV] 0-50	50-100	100-200	>200	$ZH \to \nu\bar{\nu}bb$ E_T^{miss} [GeV] 120-160	160-200	>200
Number of events for $80 < m_{b\bar{b}} < 150$ [GeV]											
Signal	1.3 ± 0.1	1.8 ± 0.2	1.6 ± 0.2	0.4 ± 0.1	5.0 ± 0.6	5.1 ± 0.6	3.7 ± 0.4	1.2 ± 0.2	2.0 ± 0.2	1.2 ± 0.1	1.5 ± 0.2
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B-tag Eff	1.4	1.0	0.3	4.8	0.9	1.3	0.9	7.2	4.1	4.2	5.5

- **B-tagging efficiency** : **~1-7 %**
  - B-tagging efficiency uncertainty per jet presently from 5 to 19% depending on pT(jet).
  - Most of the overall normalization uncertainty cancels out when determining background normalizations on data, but effect of distortions on m(bb) and p_T(W/Z) carefully evaluated.

Leading background uncertainties

Bin	$ZH \to \ell^+\ell^- bb$ p_T^Z [GeV] 0-50	50-100	100-200	>200	$WH \to \ell\nu bb$ p_T^W [GeV] 0-50	50-100	100-200	>200	$ZH \to \nu\bar{\nu} bb$ E_T^{miss} [GeV] 120-160	160-200	>200
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B-tag Eff	1.4	1.0	0.3	4.8	0.9	1.3	0.9	7.2	4.1	4.2	5.5
Bkg Norm	3.6	3.4	3.6	3.8	2.7	1.8	1.8	4.5	2.7	2.2	3.2

- **Background normalization (statistical error)** : **~2-5 %**
  - Depends on amount of sideband data which determines background scale factors.

Leading background uncertainties

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Bkg Norm	3.6	3.4	3.6	3.8	2.7	1.8	1.8	4.5	2.7	2.2	3.2
Jets/E_T^{miss}	2.1	1.2	2.7	5.1	1.5	1.4	2.1	9.5	7.7	8.2	12.1

- **Jet calibration / Missing ET** : **2-10 % (8-12% in ννbb channel)**
  - Pile-up corrections applied to jets to reduce uncertainty due to pile-up
  - Missing ET uncertainty dominant systematics in ZH → ννbb analysis.

Leading background uncertainties

Bin	$ZH \to \ell^+\ell^- bb$ p_T^Z [GeV] 0-50	50-100	100-200	>200	$WH \to \ell\nu bb$ p_T^W [GeV] 0-50	50-100	100-200	>200	$ZH \to \nu\bar{\nu}bb$ E_T^{miss} [GeV] 120-160	160-200	>200
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Bkg Norm	3.6	3.4	3.6	3.8	2.7	1.8	1.8	4.5	2.7	2.2	3.2
Jets/E_T^{miss}	2.1	1.2	2.7	5.1	1.5	1.4	2.1	9.5	7.7	8.2	12.1
Leptons	0.2	0.3	1.1	3.4	0.1	0.2	0.2	1.7	0.0	0.0	0.0
Luminosity	0.2	0.1	0.2	0.4	0.1	0.1	0.1	0.2	0.2	0.5	0.7
Pile Up	0.9	1.6	0.5	1.3	0.1	0.2	0.8	0.5	1.6	2.5	3.0
Theory	5.2	1.3	4.7	14.9	2.2	0.3	1.6	14.8	2.9	4.0	7.7
Total Bkg	6.9	4.3	6.6	17.3	3.9	2.7	3.4	19.6	9.7	10.6	16.0

- **Total background uncertainty** : **~3-20 %**
  - The highest p_T bins suffer from the highest uncertainties, which limits the improvements from the better S/B.

Leading signal uncertainties

Bin	$ZH \to \ell^+\ell^- bb$ p_T^Z [GeV]				$WH \to \ell\nu bb$ p_T^W [GeV]				$ZH \to \nu\bar{\nu} bb$ E_T^{miss} [GeV]		
	0-50	50-100	100-200	>200	0-50	50-100	100-200	>200	120-160	160-200	>200
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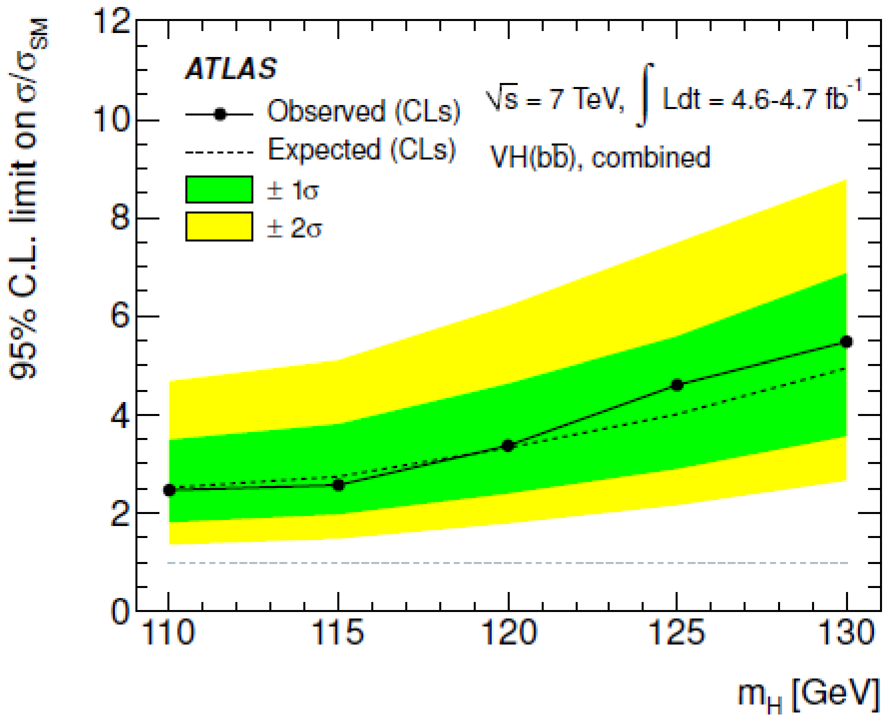
Components of the Signal Relative Systematic Uncertainties [%]											
B-tag Eff	6.4	6.4	7.0	13.7	6.4	6.4	7.0	12.1	7.1	8.2	9.2
Jets/E_T^{miss}	4.9	3.2	3.5	5.5	5.8	4.6	3.7	3.3	7.3	5.1	6.3
Leptons	0.9	1.2	1.7	2.6	3.0	3.0	3.0	3.2	0.0	0.0	0.0
Luminosity	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9
Pile Up	0.5	1.1	1.8	2.2	1.2	0.3	0.3	1.6	0.2	0.2	0.0
Theory	4.6	3.6	3.3	5.3	4.4	4.7	5.0	8.0	3.3	3.3	5.6
Total Signal	10.1	9.1	9.6	16.5	11.4	10.8	11.0	16.0	11.8	11.4	13.4

- **Total signal uncertainty** : **~9-17 %**
  - B-tagging: 5-15%
  - JES/MET: ~5% (~6% for vvbb)
  - Theory inclusive + differential uncertainties: ~3-8% [CERN Yellow Reports] (EW NLO corrections also applied: reduces cross section at high pT)

Combined result

arXiv:1207.0210 (submitted to Phys. Rev. Lett. B)

- Hypothesis testing based on likelihood with m(bb-jet) distribution for signal and background in the signal region (80 GeV < m(bb) < 150 GeV).
- Systematic uncertainties through dependence of normalization and m(bb) shape on additional *nuisance* parameters, constrained within expected uncertainties.

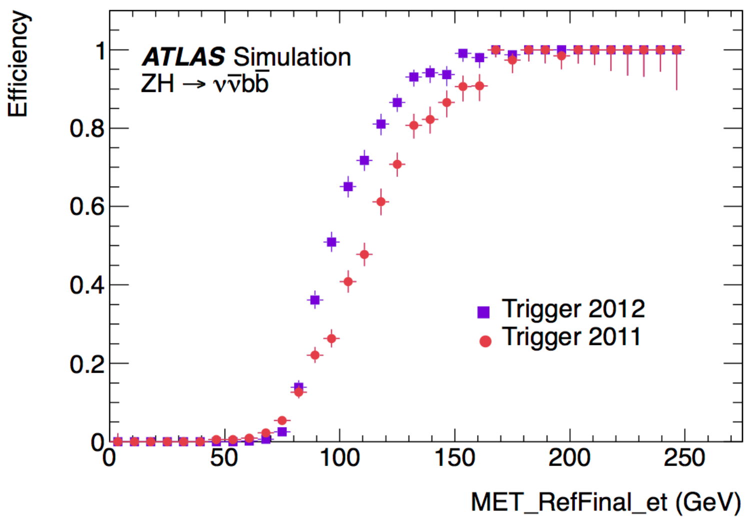


- 95% confidence level upper limits on signal extracted using **CL_s** method.
- Expected limits **from ~2.5 to ~5 times the Standard Model** expectation, observed limits close to expectations (**exclude ~4.6xSM at m(H)=125 GeV**).
- Most of the sensitivity from WH → ℓνbb and ZH → ννbb.
- **Looking forward to release 2012 data results!**
- In the pipeline: better m(bb) resolution, MV analysis, lower theory systematics.

Backup slides

Trigger and leptonic mode selection

- $WH \rightarrow \ell\nu b\bar{b}$ Single lepton trigger (ε~100% w.r.t. offline for e, ε~90% for μ)
- $ZH \rightarrow \ell^+\ell^- b\bar{b}$ Single lepton+di-electron trigger (ε~100% for ee, ~95% for μμ)
- $ZH \rightarrow \nu\bar{\nu} b\bar{b}$ ETmiss trigger with 70 GeV threshold (ε >95% w.r.t. offline selection)



- **Trigger** turn-on curve for ETmiss trigger measured in W+jet data events with ~1% level accuracy and extrapolated to ZH → ννbb signal using MC.
- **Missing ET** reconstructed from calorimeter energy clusters with |η|<4.9 (+corrections). Muons included in the sum. Supplemented by track-based missing pT (pTmiss).

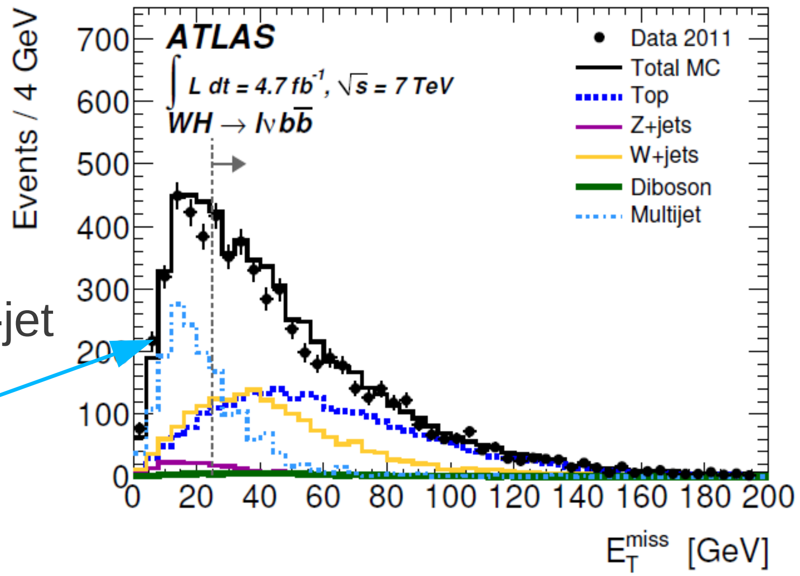
- **Electrons**: exploit shower shapes + apply quality requirements to matched track in Inner Detector. Tighter requirements for lνbb.
- **Muons:** combined Inner Detector – Muon System tracks for signal muons, use also Muon System only muons for veto (up to |η|=2.7).

Multi-jet background

- Suppress multi-jet background
  - **ZH → ℓℓbb** and **WH → ℓνbb**: by track- (and calorimeter-) based isolation of the selected charged leptons
  - **ZH → ννbb:** by requiring:
    - |Δφ(ETmiss,pTmiss)| < π/2
    - |Δφ(ETmiss,jets)| > 1.8
- Estimate from data
  - **ZH → ℓℓbb** (**WH → ℓνbb**): multi-jet templates from **looser lepton ID** (**anti-isolation**), then estimate based on fit to **m(ℓℓ)** (**Etmiss**)

Multi-jet bkg

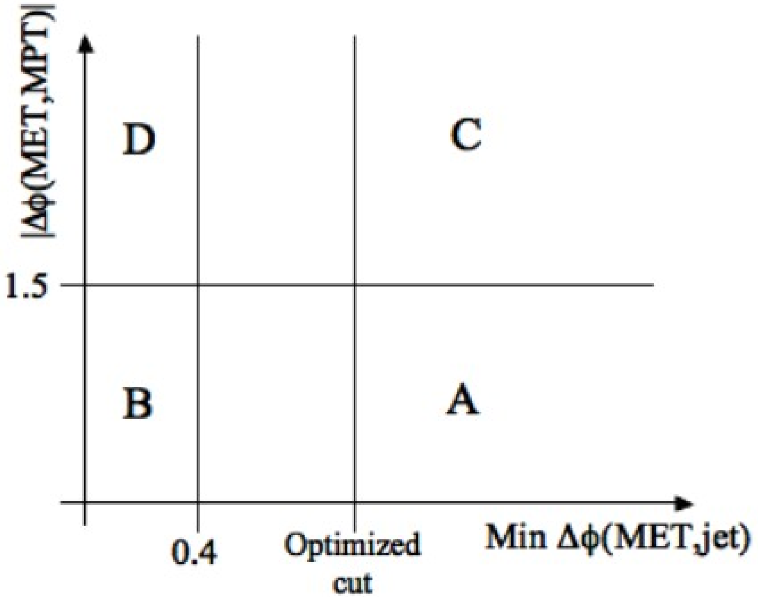
WH → ℓνbb



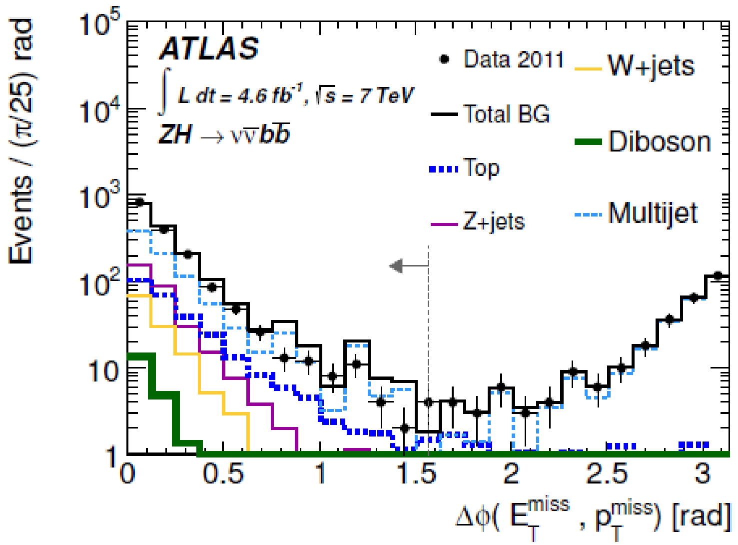
Multi-jet background (II)

- **ZH → ννbb:** exploit lack of correlation of **Δϕ(ETmiss,pTmiss)** and **Δϕ(ETmiss,jets)** for multi-jet background to get estimate in signal region:

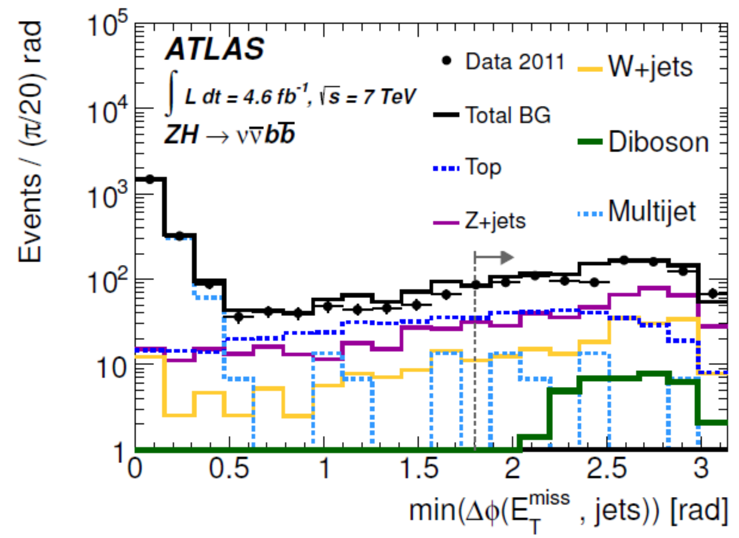
- $$N_{QCD}(A) = \frac{N(B)}{N(D)} \times N(C)$$



Δϕ(ETmiss,pTmiss)

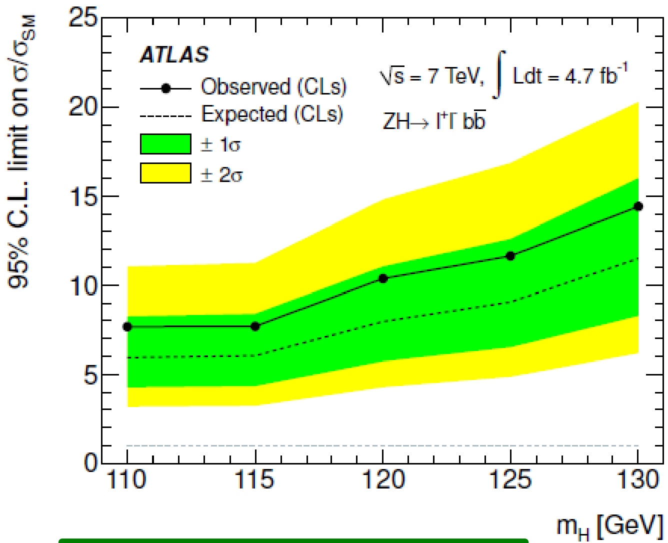


Δϕ(ETmiss,jets)

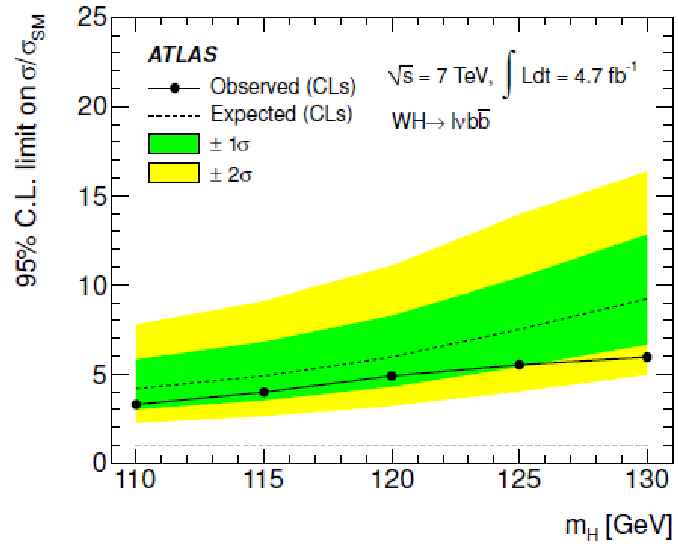


Separate limits

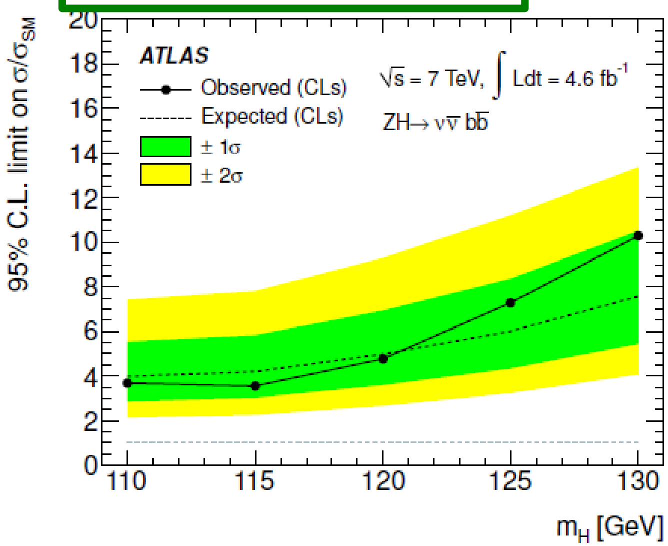
$ZH \rightarrow \ell^+\ell^- b\bar{b}$



$WH \rightarrow \ell\nu b\bar{b}$

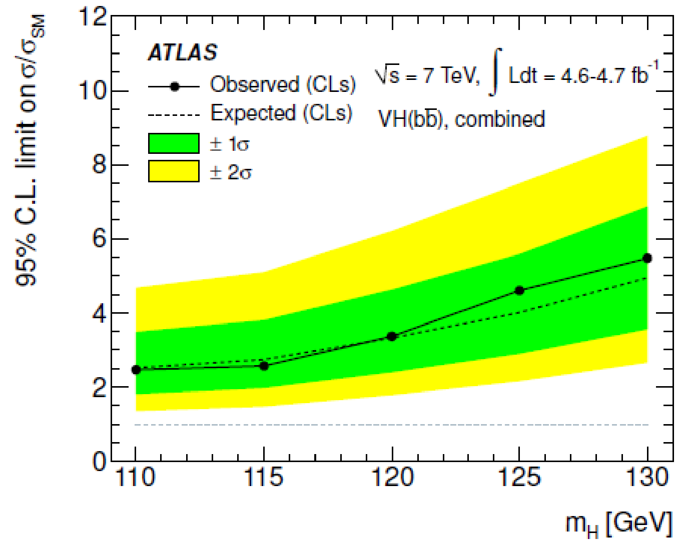


$ZH \rightarrow \nu\bar{\nu}b\bar{b}$



Combination

(b)



(c)

(d)