$A \to Zh \to ll\tau\tau$

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on behalf of the ATLAS collaboration

Motivation

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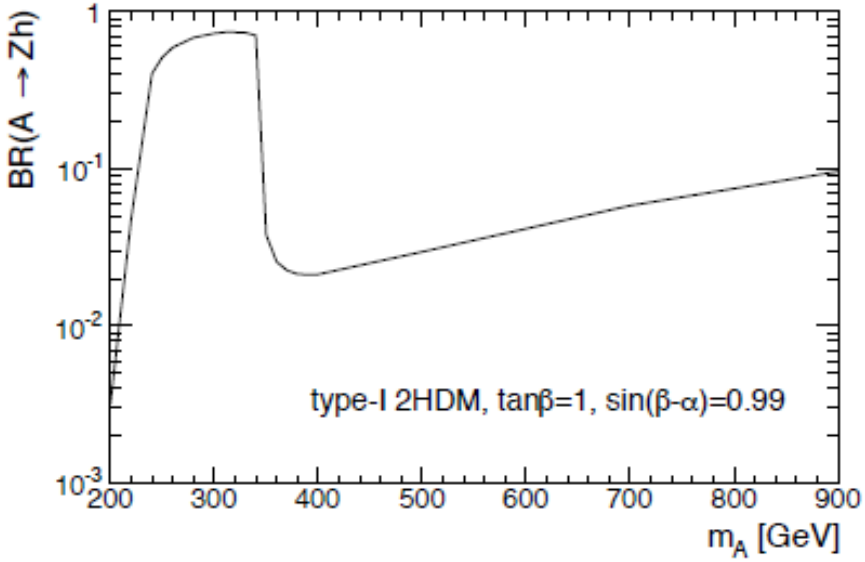
- The $A \rightarrow Zh$ channel is relevant for many BSM Higgs scenarios, including 2 Higgs doublet models (2HDM). 2HDM are phenomenological models with an extension of the SM Higgs sector by an additional doublet leading to 5 Higgs bosons: $h, H, A, H^{\pm}$

- Branching ratio to Zh dominates for *A* mass below $t\bar{t}$ mass



Overview

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- ATLAS has published a *Search for a CP-odd Higgs boson decaying to Zh in pp collisions at* $\sqrt{s} = 8$ *TeV with the ATLAS detector* (*Physics Letters B 744 (2015) 163-183*)

- The paper included the $ll\tau\tau$, $llbb$ and $\nu\nu$bb final states. This talk will focus on the $ll\tau\tau$ channels

- The $ll\tau\tau$ analysis was split into three channels depending on the final state of the taus:

$\boldsymbol{ll\tau_{lep}\tau_{lep}}$ $\boldsymbol{ll\tau_{lep}\tau_{had}}$ $\boldsymbol{ll\tau_{had}\tau_{had}}$

Common Selection

Single Lepton (and Dilepton for $\tau_{lep}\tau_{lep}$) Triggers

Two Same-Flavour, Opposite Sign (OS) Charge, Isolated Leptons (μ/e)

$80\ \text{GeV} < M_{ll} < 100\ \text{GeV}$

For $\tau_{had}\tau_{had}$ and $\tau_{lep}\tau_{had}$: $75 < M_{\tau\tau}^{MMC} < 175\ \text{GeV}$

For $\tau_{lep}\tau_{lep}$: $90 < M_{\tau lep,\tau lep}^{MMC} < 190\ \text{GeV}$

LepLep

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- Main background is diboson which is estimated from simulation.

- The LepLep channel is sub-divided into same flavor (SF) and different flavor (DF) regions (referring to leptons from Higgs decay)

$A \rightarrow Zh \rightarrow ll\tau_{lep}\tau_{lep}$ Selection: DF

μ and e of OS charge

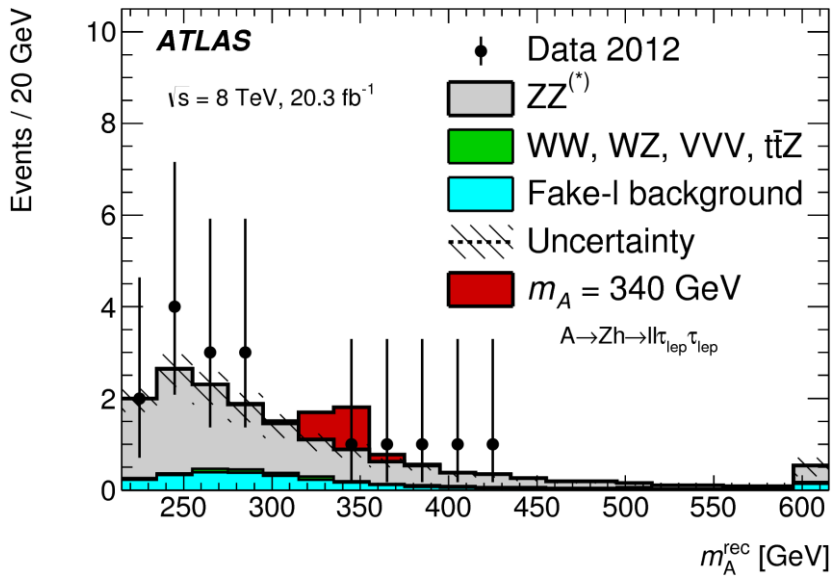
$A \rightarrow Zh \rightarrow ll\tau_{lep}\tau_{lep}$ Selection: SF

2 μ or e of OS charge

$m_{\mu\mu/ee} < 80$ GeV or $m_{\mu\mu/ee} > 100$ GeV

$\Delta\phi^{Z,ETmiss} > \pi/2$

$E_T^{miss} > 30$ GeV



LepHad

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- Main backgrounds were Z+Jets (reducible) and diboson (irreducible), with similar contributions

- Irreducible backgrounds were estimated from simulation

- Reducible backgrounds (i.e. jets faking taus) were estimated using the a template method:
  - Use control region (B+C+D) to model background shape in signal region (A)
  - Scale background using normalization factor from Higgs mass sidebands (outside 75-175 GeV). $f_{scale} = \frac{A_{h-side}}{(B+C+D)_{h-side}}$

- Same method used in HadHad channel

$A \rightarrow Zh \rightarrow ll\tau_{lep}\tau_{had}$ Selection

Exactly 1 additional μ/e

Exactly 1 τ_{had}

τ and μ/e have OS charge

Inverted tau IDs / SR tau IDs	OS	SS
SR tau IDs	A	B
Inverted tau IDs	C	D

HadHad

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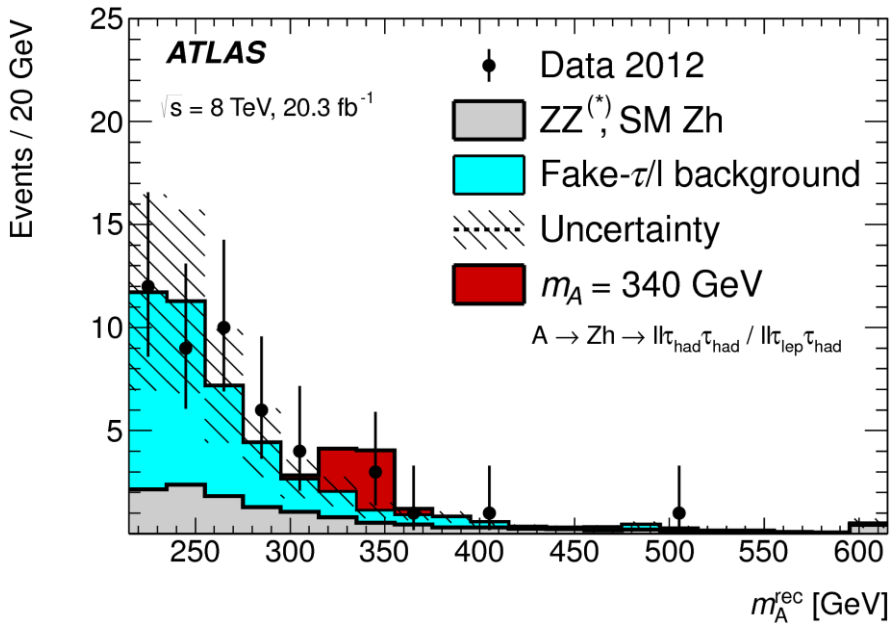
- Main background is Z+Jets.
- Small irreducible background also estimated using simulation
- Reducible Z+Jets background uses same template method described earlier

$A \rightarrow Zh \rightarrow ll\tau_{had}\tau_{had}$ Selection

No additional μ/e

2 OS charge τ_{had}

$p_{T,Z} > \min[\,(0.64 m_A - 131),\, 125]$ GeV



Results and Interpretation

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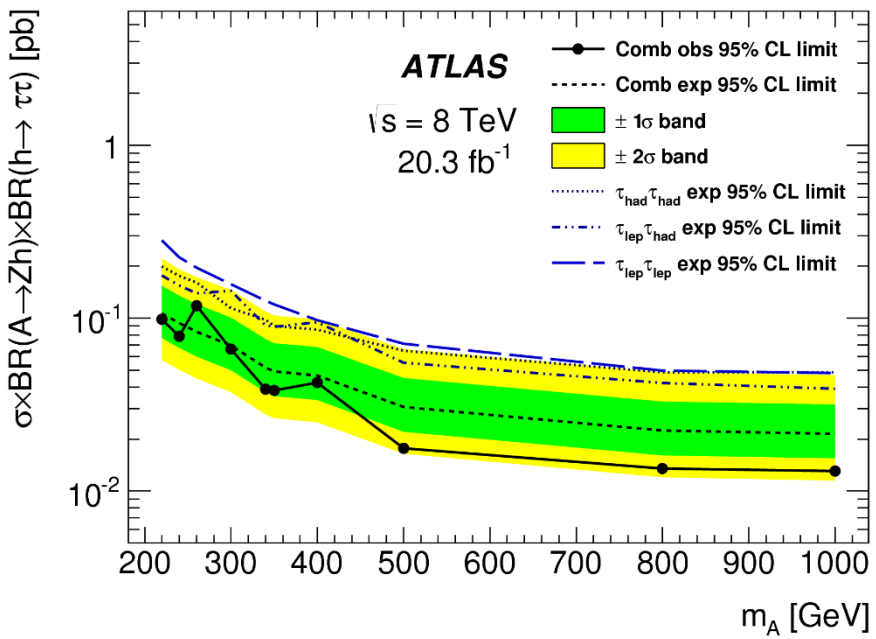
- No excess with respect to SM observed
- Upper limits on cross section times branching ratio set
- Results were interpreted in CP-conserving 2HDM scenarios

The number of predicted and observed events for the $\ell\ell\tau\tau$ channels.

	Expected background	Data
$\ell\ell\tau_{\text{had}}\tau_{\text{had}}$	28 ± 6	29
$\ell\ell\tau_{\text{lep}}\tau_{\text{had}}$	17 ± 4	18
$\ell\ell\tau_{\text{lep}}\tau_{\text{lep}}$ (SF)	9.5 ± 0.6	10
$\ell\ell\tau_{\text{lep}}\tau_{\text{lep}}$ (DF)	7.2 ± 0.7	7



2HDM interpretation of limits

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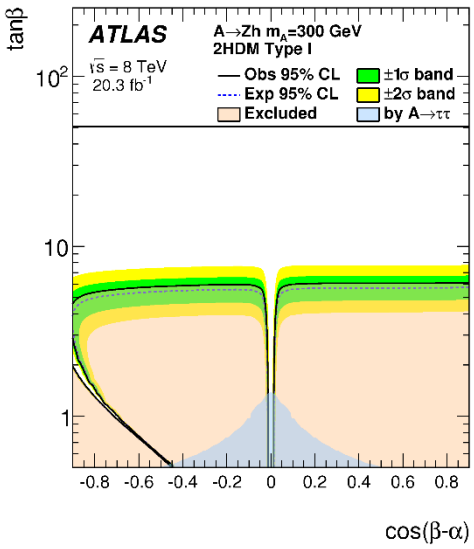

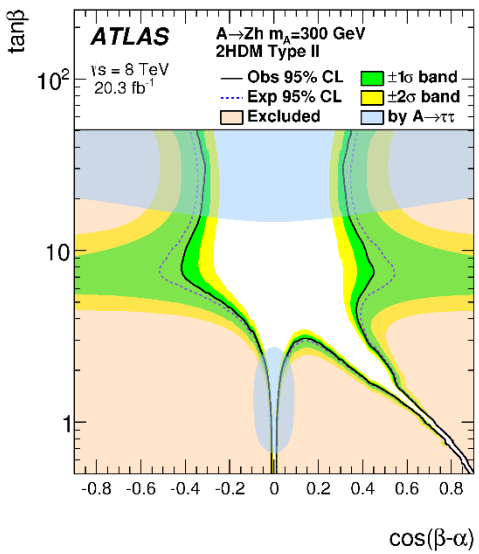

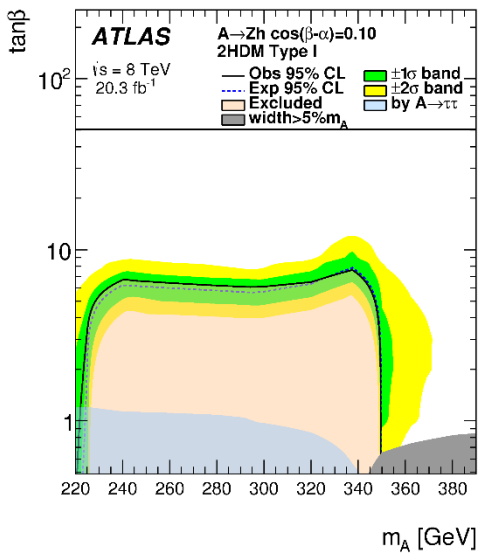

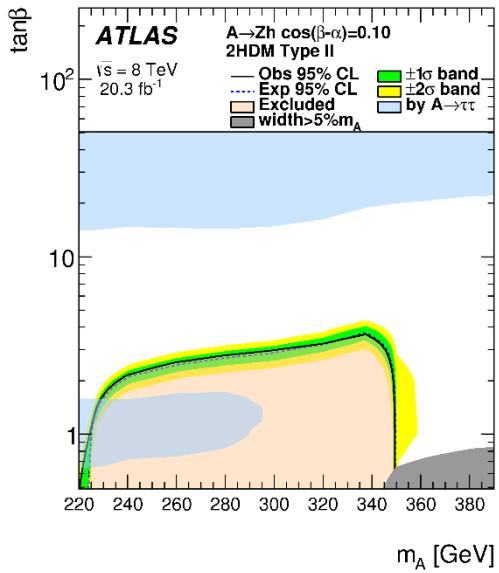

- Interpretation of the cross-section limits in the context of 2HDM type-I and type-II as a function of parameter $\tan(\beta)$, m_A and $\cos(\beta-\alpha)$. Blue shaded area is due to constraints derived by considering $A \to \tau\tau$ mode of neutral MSSM Higgs to $\tau\tau$ search
- This search provided a nice complementarity to other BSM searches

Thanks!

BACKUP

Analysis details

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- For the LepLep and LepHad final states, the Z lepton pair was assigned based on the OS lepton pair that had the reconstructed mass closest to the Z mass.

- For all 3 $ll\tau\tau$ channels, The resolution of the reconstructed *A* boson mass is further improved by using a mass difference variable:
  $m_A^{rec} = m_{ll\tau\tau} - m_{ll} - m_{\tau\tau} + m_Z + m_h$, where m_Z is the known mass of the *Z*, $m_h = 125$ GeV, m_{ll} is the invariant of the Z leptons, and $m_{ll\tau\tau}$ is the $ll\tau\tau$ invariant mass. The $m_{\tau\tau}$ mass is estimated with the Missing Mass Calculator (MMC).

- In the LepLep channel, events with at least one lepton which is a misidentified jet or from a heavy flavor quark decay amount to 35% (5%) for DF (SF) subchannels. These fake lepton events are mostly from Z+Jets production and are estimated using a control region where one or both Higgs leptons fail the isolation criteria.

- HadHad channels uses “Loose” taus. LepHad tau must pass “Medium”.

- The LepHad channel also has a small (11%) contribution from SM Higgs production in association with a Z boson.

Systematics

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- For backgrounds with real $ll\tau\tau$ objects, the biggest source of systematic uncertainty for the LepLep, LepHad channels was the uncertainty on the theoretical cross sections used in the normalization, amounting to about 6.4% and 5%, respectively. In the HadHad channel the largest contribution comes from the τ_{had} identification and energy scale and amounts to 8.9%.

- The fake τ_{had}/l background systematic uncertainty for the $\tau\tau$ channels is dominated by the statistical uncertainty on data in control regions used for the background normalization. It amounts to 38% and 25% for the LepHad and HadHad, respectively. This is mostly due to low statistics in OS/passID region (“A” region) in Higgs sidebands where normalization scale is computed. For LepLep, the normalization uncertainty is 65% (25%) for the SF (DF) categories.

m_A distributions per channel

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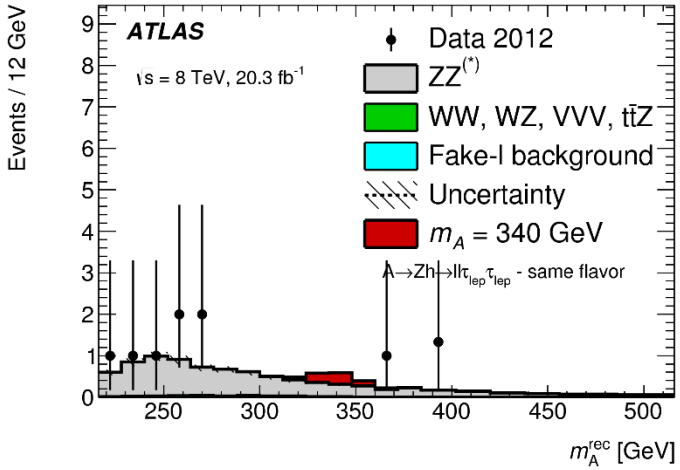

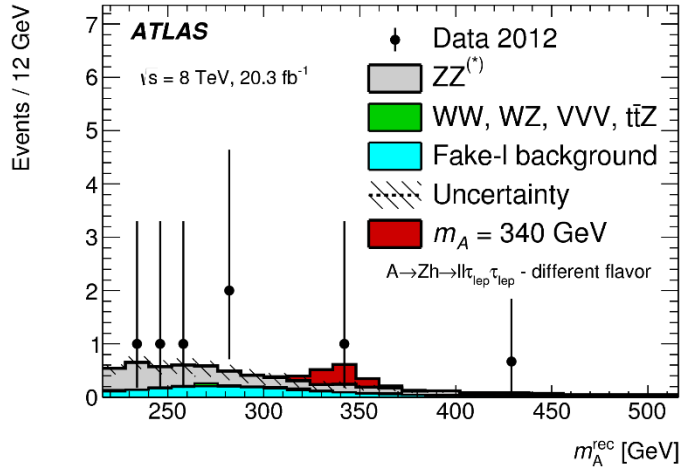

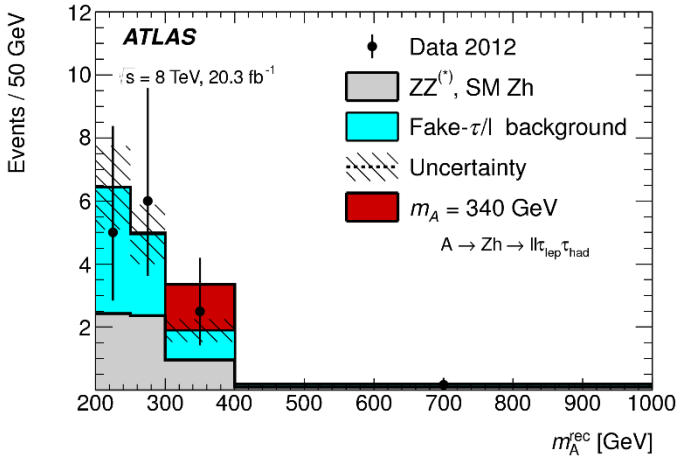

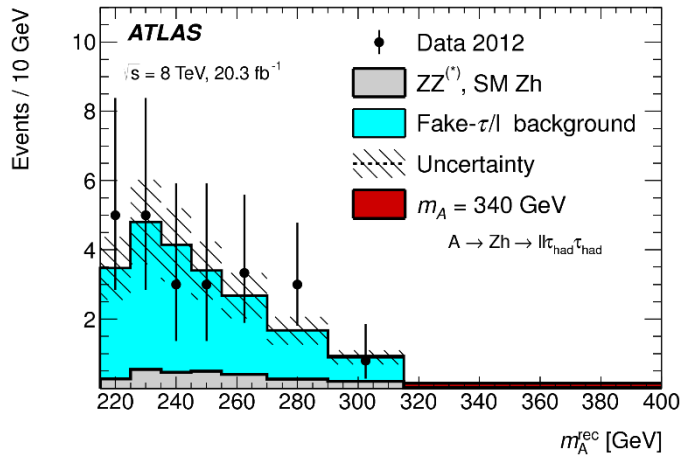

$m_{\tau\tau}^{MMC}$ distributions per channel

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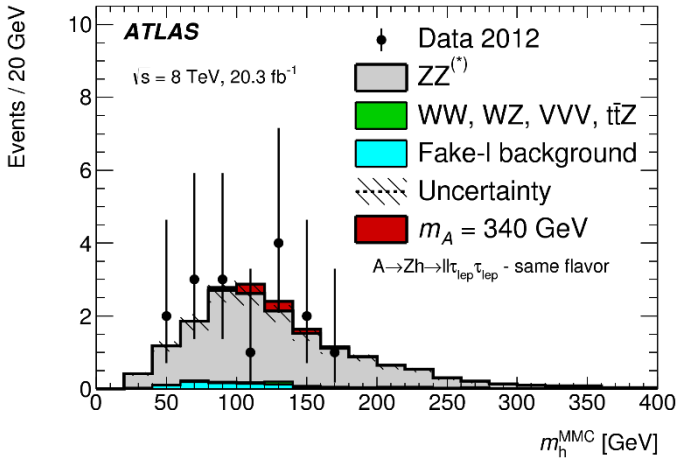

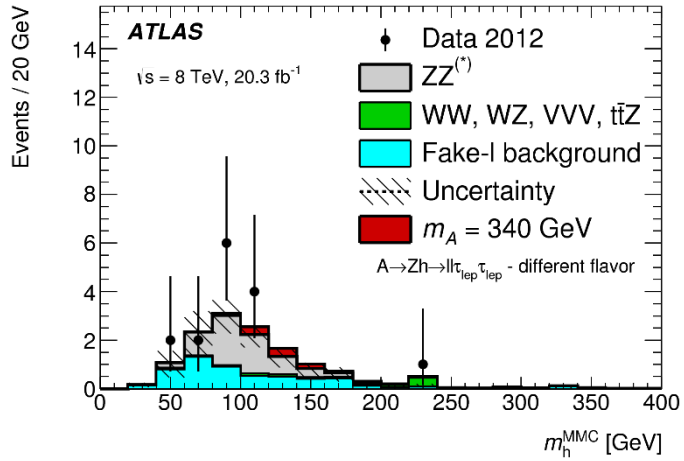

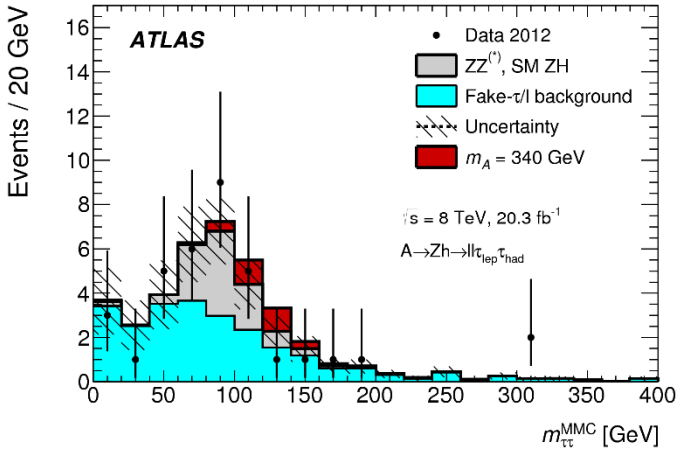

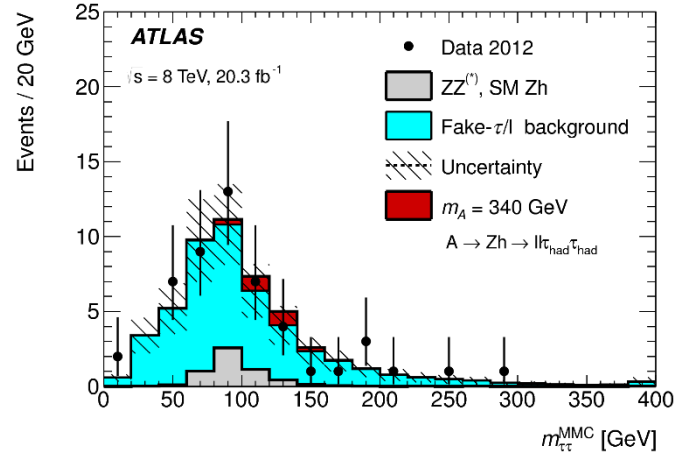

2HDM interpretation of limits

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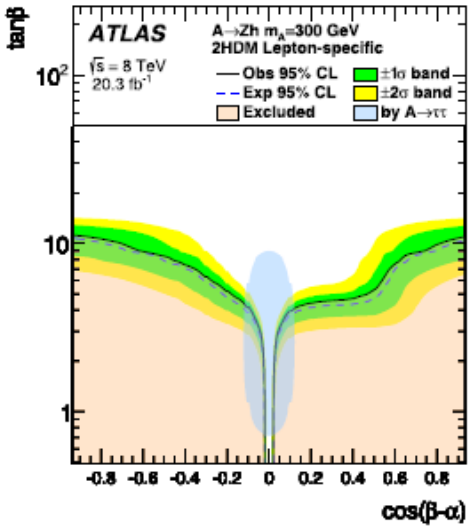
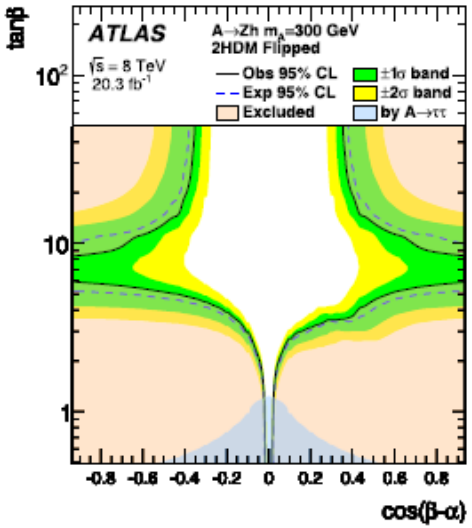
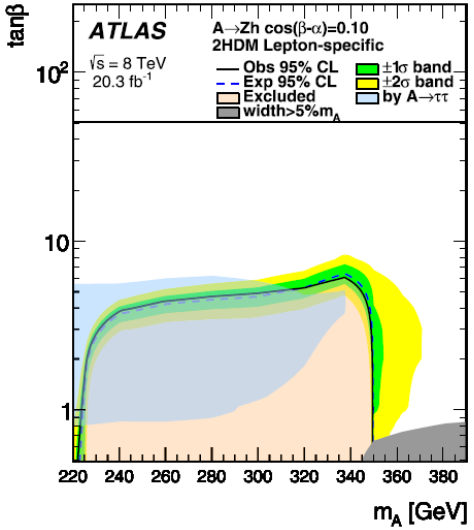


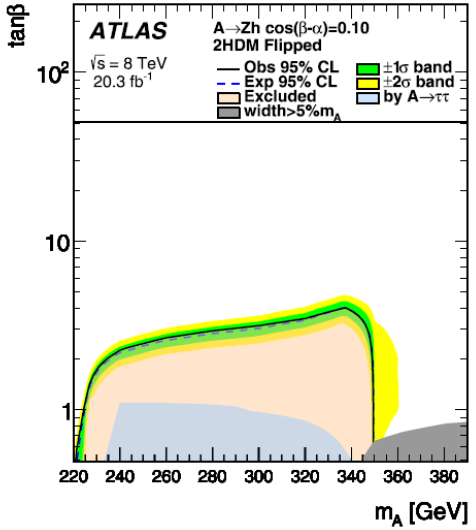
(c) Lepton-specific 2HDM, $m_A = 300$ GeV



(d) Flipped 2HDM, $m_A = 300$ GeV



(c) Lepton-specific 2HDM, $\cos(\beta - \alpha) = 0.1$



(d) Flipped 2HDM, $\cos(\beta - \alpha) = 0.1$

$llbb$ and $ll\tau\tau$ limits

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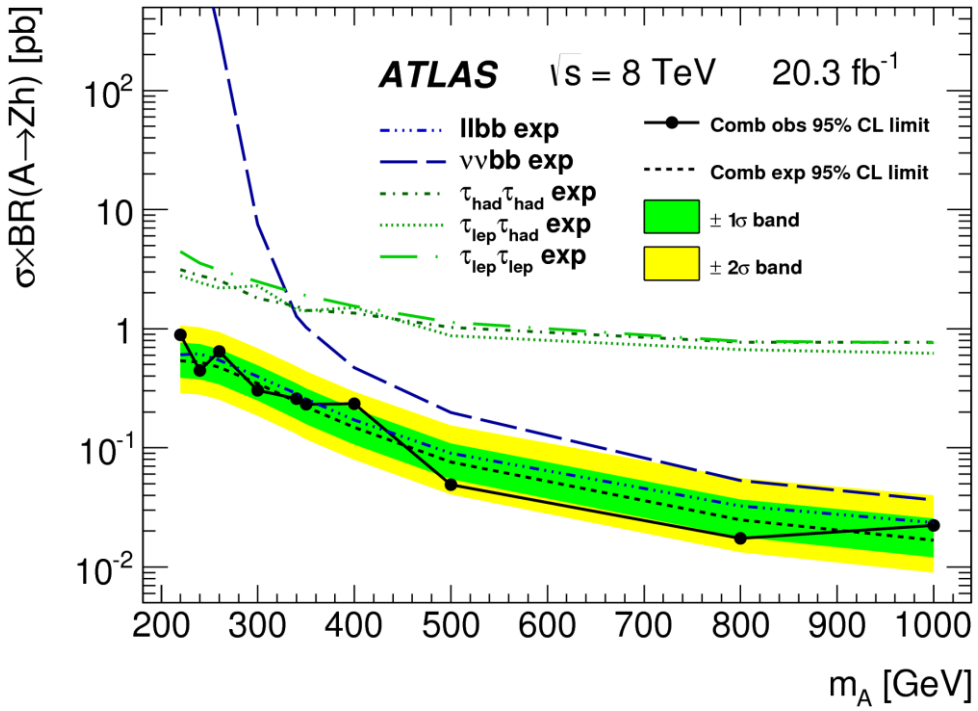

$h \to bb$ channel results

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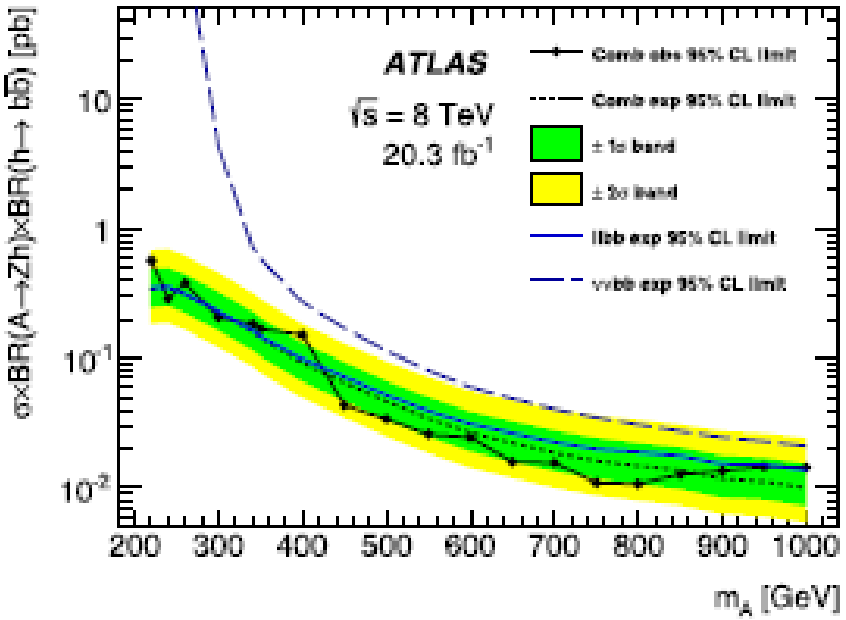
Table 2
Predicted and observed number of events for the $\ell\ell bb$ and $\nu\nu bb$ final states shown after the profile likelihood fit to the data.

	$(\ell\ell bb)$	$\nu\nu bb$
Z + jets	1443 ± 60	225 ± 11
W + jets	–	55 ± 8
Top	317 ± 28	203 ± 15
Diboson	30 ± 5	10.8 ± 1.6
SM Zh, Wh	31.7 ± 1.8	22.5 ± 1.2
Multi-jet	20 ± 16	3.2 ± 3.1
Total background	1843 ± 34	521 ± 12
Data	1857	511



(b) $A \to Zh$, $h \to bb$

$h \to bb$ final distributions

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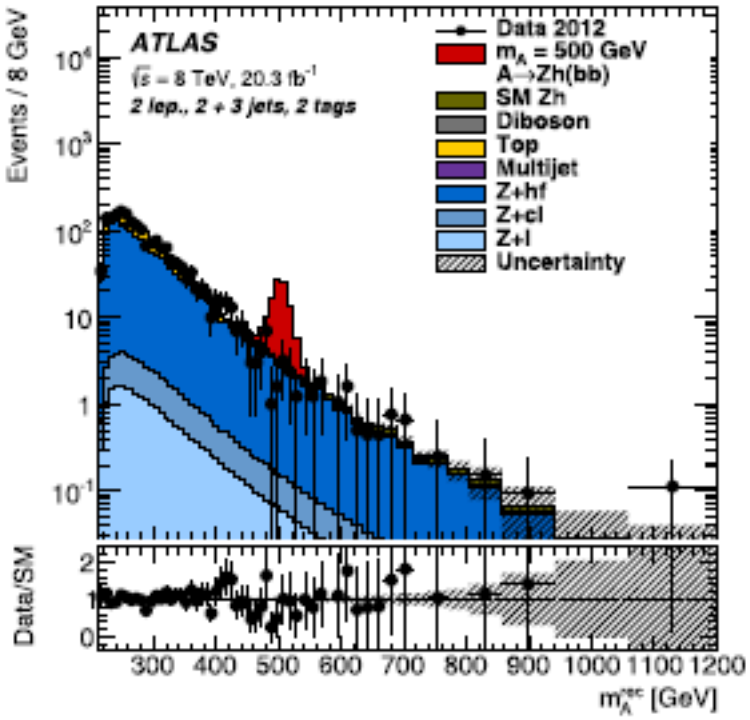
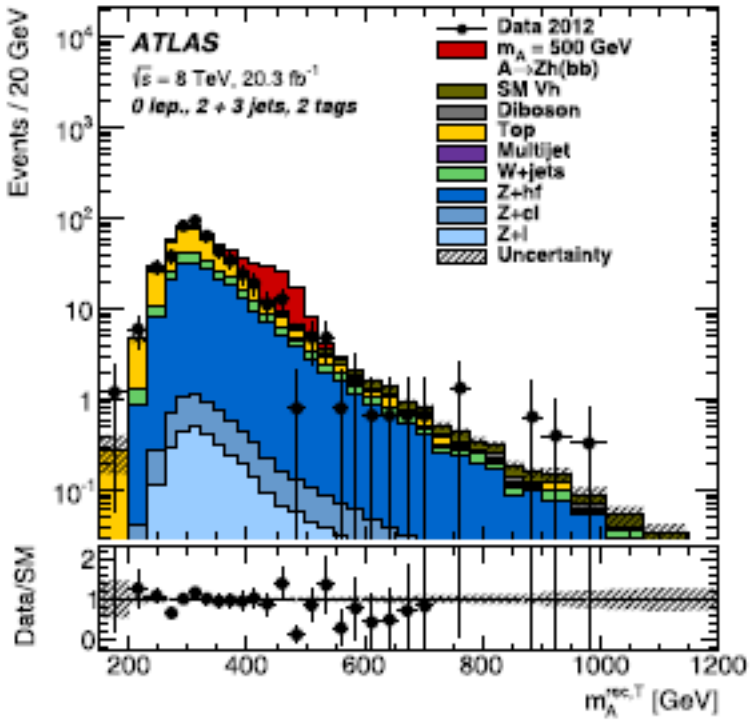


(a) $\ell\ell bb$



(b) $\nu\nu bb$