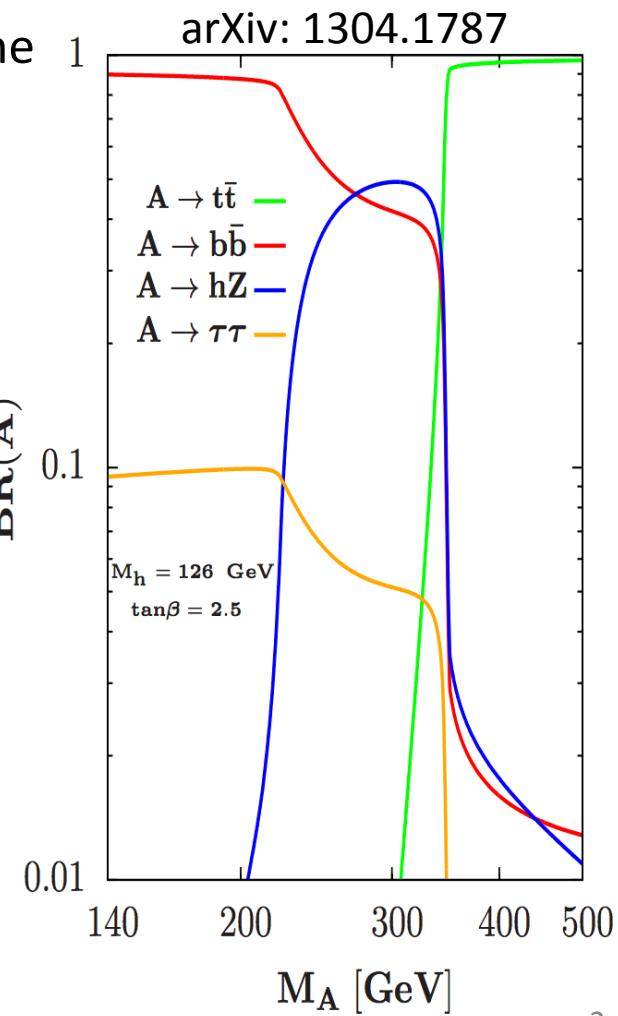
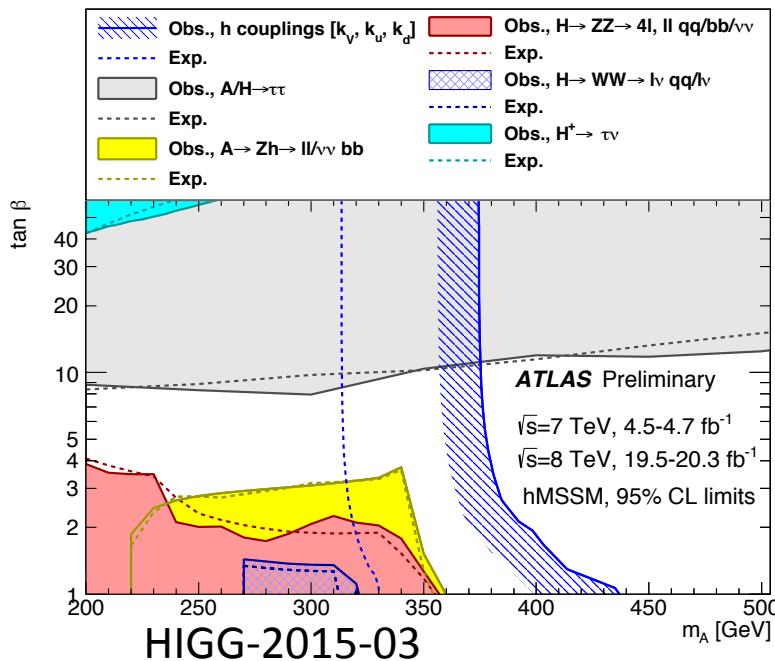


ATLAS Results in the Search for a CP-odd Higgs Boson Decaying to Z ν , in Final States with Two τ 's and Two e or μ

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Motivation

- The existence of a neutral, pseudoscalar A boson is predicted in Two Higgs Doublet Models.
- $A \rightarrow Zh$ is the dominant decay mode just below the $t\bar{t}$ threshold.
 - Complementary to other Higgs searches.
 - Searches for $A \rightarrow Zh$ target low $\tan(\beta)$ and $\cos(\beta-\alpha)$ in the decoupling limit



Analysis Overview

This talk covers the search for the decay $A \rightarrow Z h \rightarrow ll\tau\tau$, in three channels that are defined by the τ decays.

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 $\tau_{lep}\tau_{had}$: $75 < M_{\tau\tau} < 175 \text{ GeV}$

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

$A \rightarrow Z h \rightarrow ll\tau_{had}\tau_{had}$ Selection

No additional μ/e

2 OS charge τ_{had}

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

$A \rightarrow Z h \rightarrow ll\tau_{lep}\tau_{had}$ Selection

Exactly 1 additional μ/e

Exactly 1 τ_{had}

τ and μ/e have OS charge

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

μ and e of OS charge

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

2 μ or e of OS charge

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

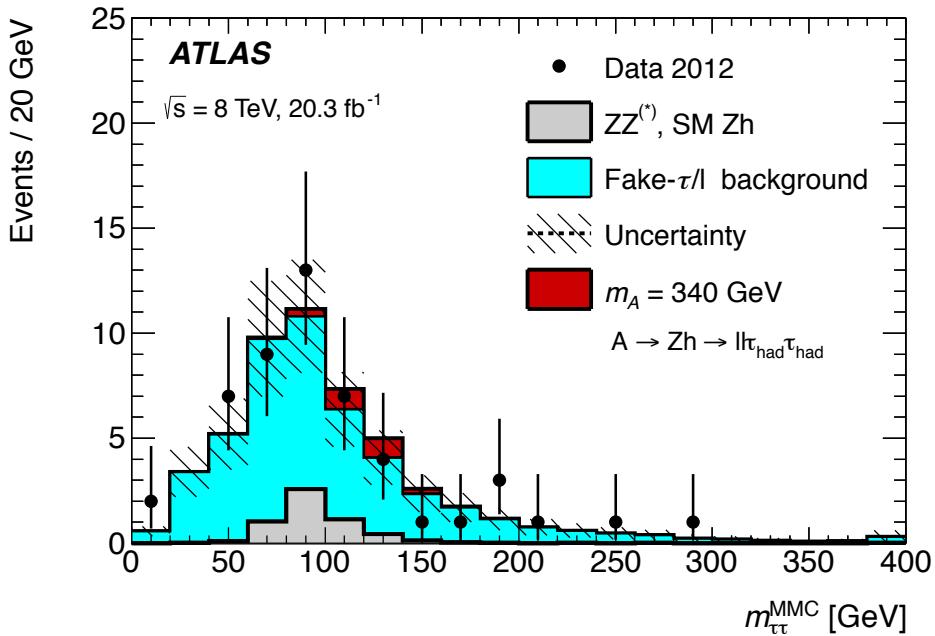
$$\Delta\phi^{Z,\text{ETmiss}} > \pi/2$$

$$E_T^{\text{miss}} > 30 \text{ GeV}$$

Event Selection: MMC and m_A^{rec}

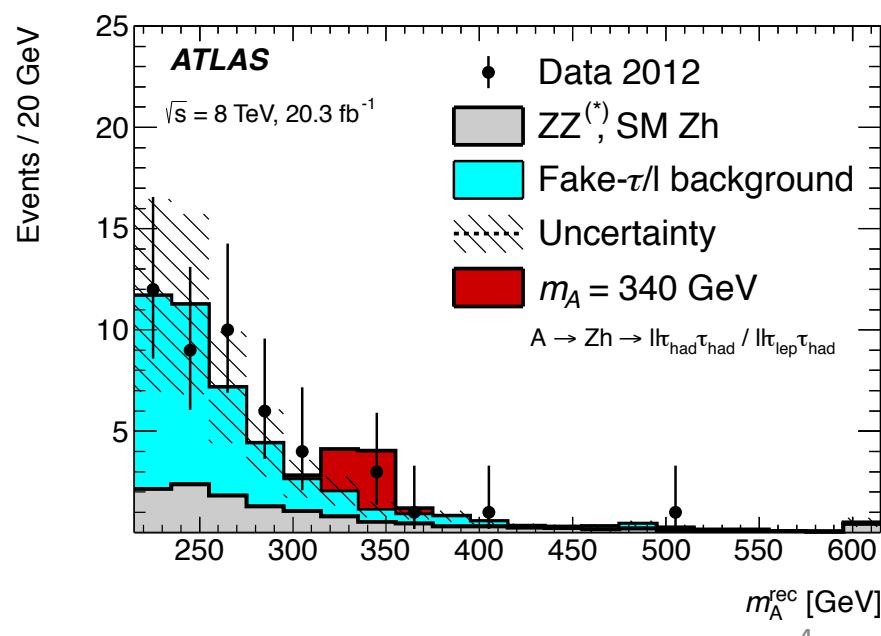
Missing Mass Calculator (MMC)

- For all channels, the MMC algorithm is used to reconstruct the mass of the h boson.
- This algorithm uses the full kinematic information of the event and the missing transverse energy, along with information from the τ decay kinematics, to find the best estimate of the di- τ system parameters.



Scaled A boson mass

- m_A^{rec} is used for setting limits/extrating signal, and it is scaled to improve resolution:
- $$m_A^{\text{rec}} = m_{ll\tau\tau} - m_{l+l-} - m_{\tau\tau} + m_Z^0 + m_h^0,$$
- where $m_Z^0 = 91.1 \text{ GeV}$ and $m_h^0 = 125 \text{ GeV}$, and $m_{ll\tau\tau}$, m_{l+l-} , and $m_{\tau\tau}$ are the reconstructed values.
- Mass resolution is $\sim 12\text{-}13 \text{ GeV}$ at $m_A = 300 \text{ GeV}$, and $\sim 35\text{-}44 \text{ GeV}$ at $m_A = 800 \text{ GeV}$.

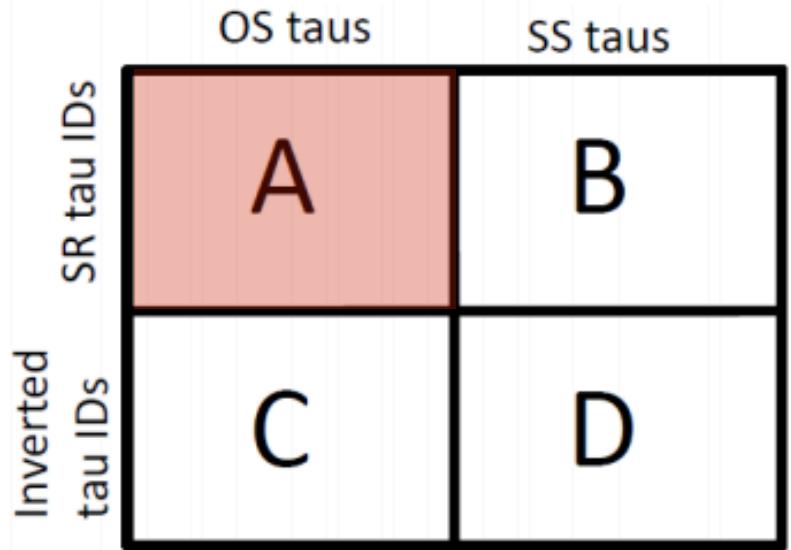


Background Estimation

- The backgrounds of these three channels come from two different sources:
 - *Irreducible backgrounds*: These primarily include ZZ diboson and SM Zh, and refer to backgrounds with all objects matched to truth information.
 - These backgrounds are estimated using simulation.
 - *Reducible backgrounds*: These are backgrounds where jets are misidentified as 1 or more τ_{had} or lepton in the event. These are dominated by Z+jets.
 - These backgrounds are estimated using data-driven methods.
 - *Other backgrounds considered*: multi-jet backgrounds are negligible, due to the requirement of 2-4 e/ μ in the event. It is also observed that backgrounds with e/ μ misidentified as τ_{had} contribute negligibly to the signal region.

Reducible: Template Method/Control Regions

- For $\text{I}\tau_{\text{had}}\tau_{\text{had}}/\text{I}\tau_{\text{lep}}\tau_{\text{had}}$, both channels use a template method:
 - Use populated control region to model background shape.
 - Determine the normalization in the h -sidebands (outside the 75-175 GeV mass window).
- For $\text{I}\tau_{\text{lep}}\tau_{\text{lep}}$, same method as the SM $h \rightarrow ZZ \rightarrow 4l$ analysis is used (arXiv:1307.1427 [hep-ex]).
 - Transfer factors are defined to extrapolate normalization of non-isolated control regions to isolated regions.

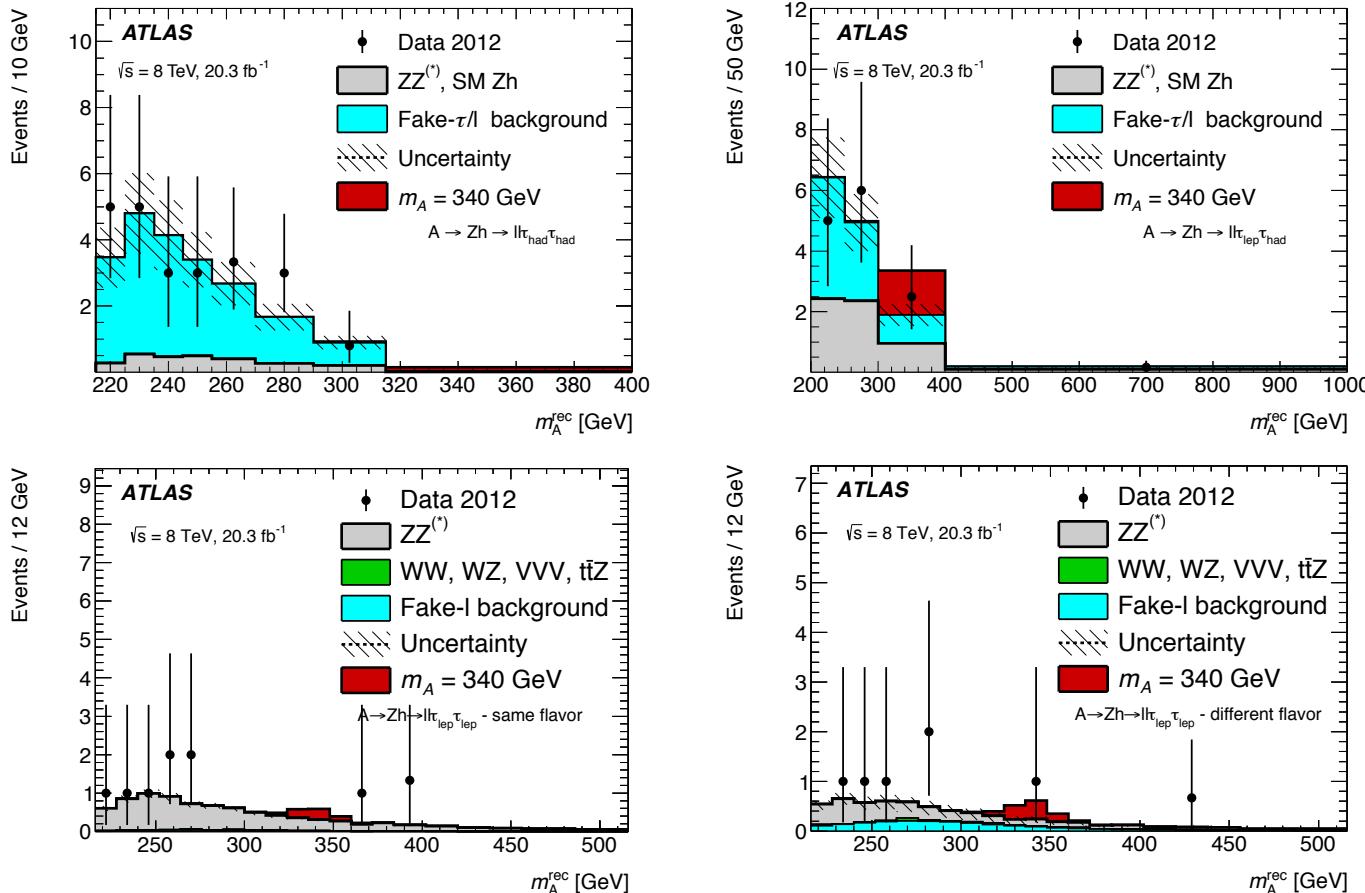


Region A = Signal Region

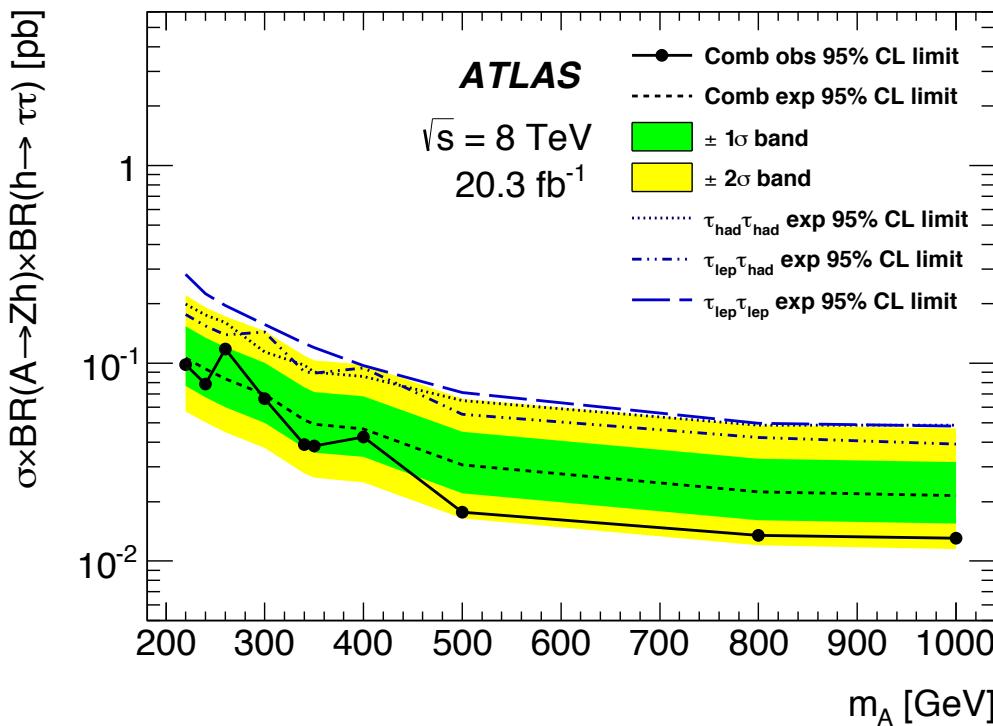
Regions B+C+D = Template Region

Final Yields

$\ell\ell\tau_{\text{had}}\tau_{\text{had}}$	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

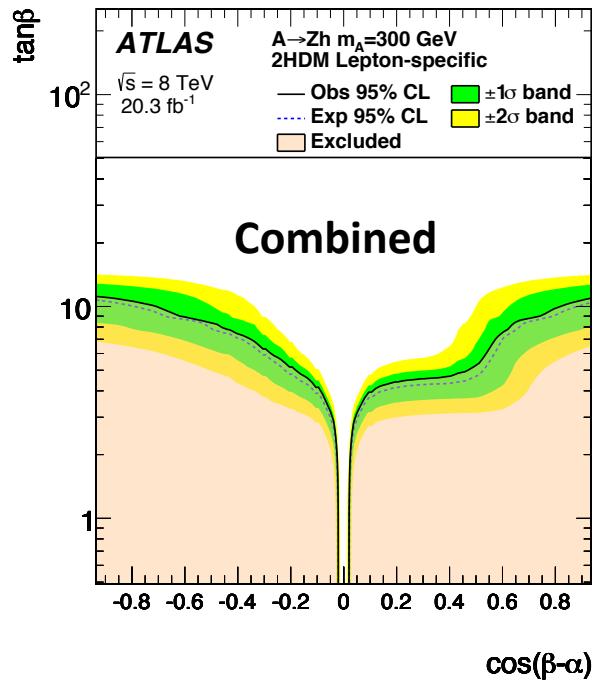
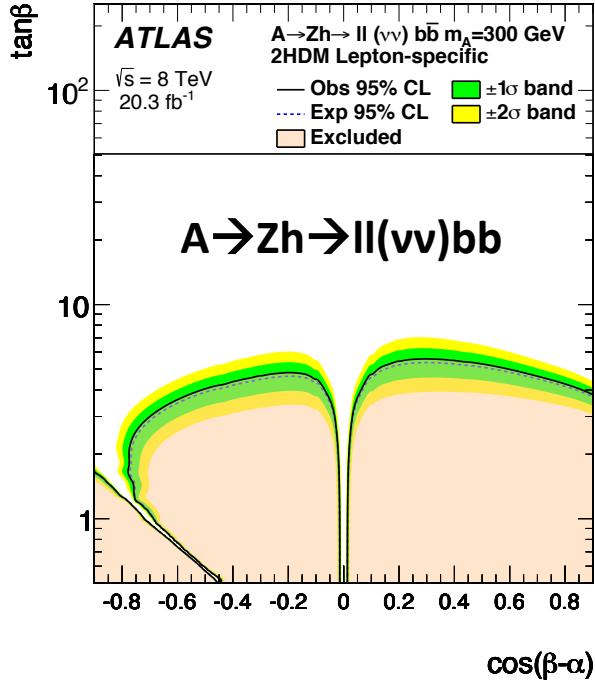
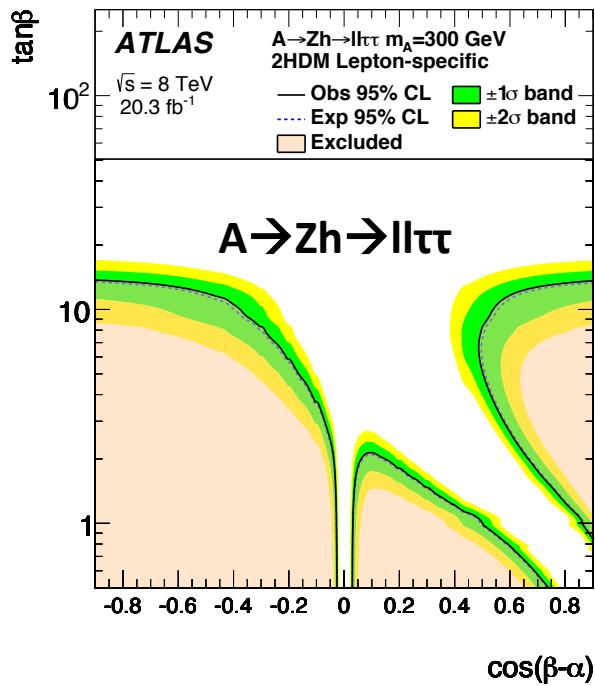


Limit Results



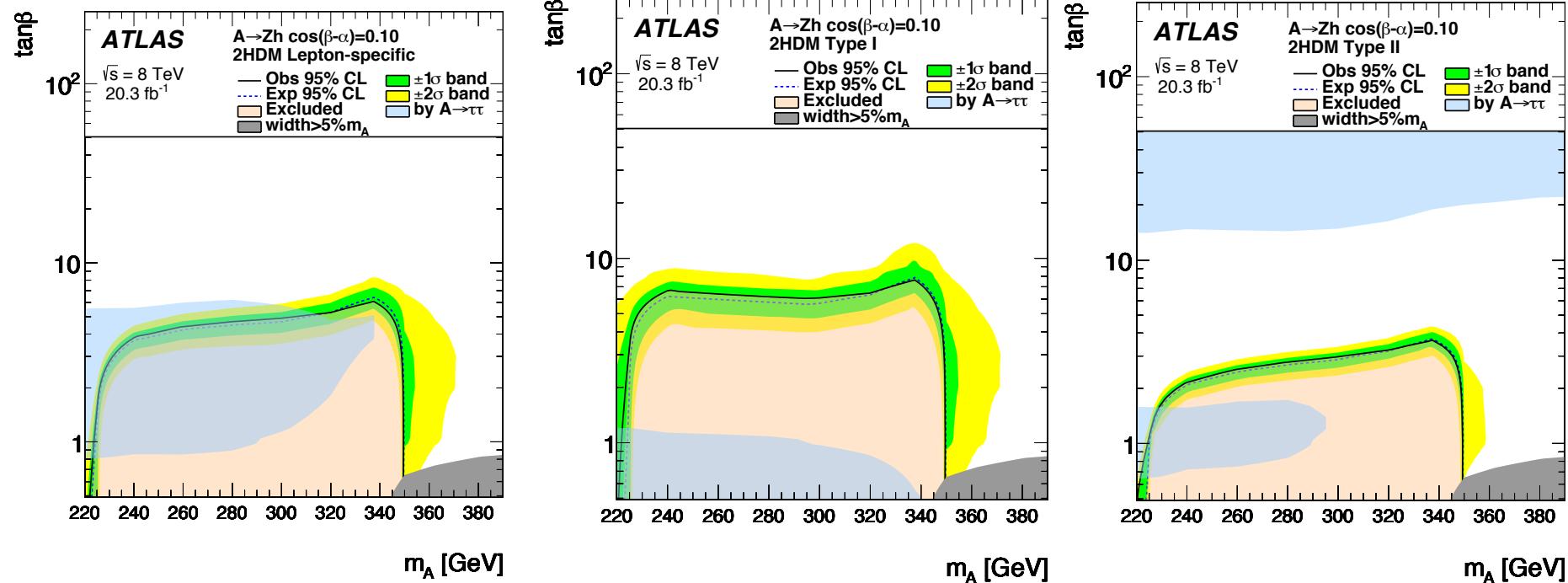
- These plots show the limits in combination and separately for the three sub-channels.
 - The black line is the combined limit
 - The colored dotted lines show the expected limit for each subchannel.

Interpretation: Lepton-Specific 2HDM



- For interpretations in 2HDM models, the $A \rightarrow \text{Zh} \rightarrow \text{ll}\tau\tau$ limit (left) is combined with that of $A \rightarrow \text{Zh} \rightarrow \text{ll}(vv)\text{bb}$ (right).
- In lepton-specific 2HDM, the complementarity of the two channels is visible.

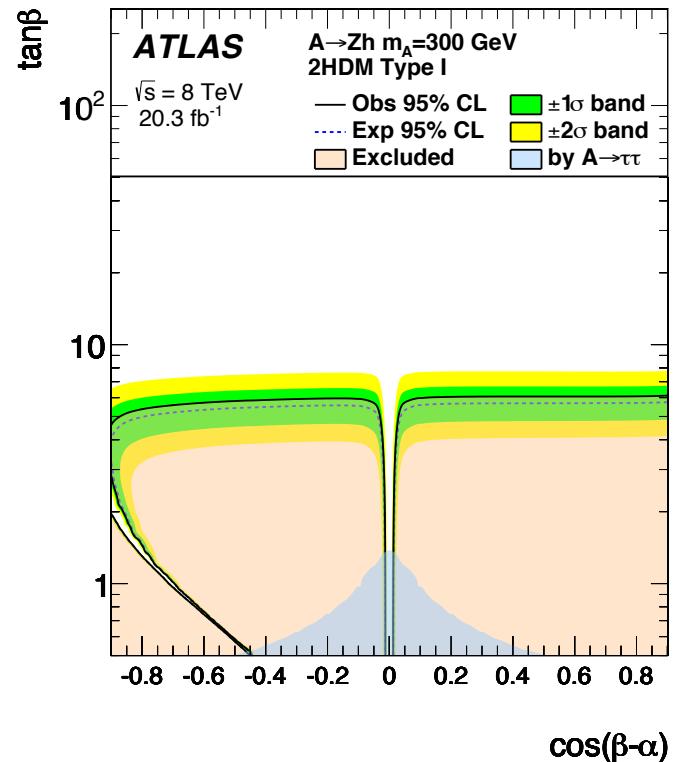
Interpretation: 2HDM



- For these limits, the $A \rightarrow Z h \rightarrow ll\tau\tau$ and $A \rightarrow Z h \rightarrow ll(vv)bb$ channels are combined, and the $A \rightarrow \tau\tau$ results are also overlaid.
- Lepton Specific (left), Type-I (middle), and Type-II (right)

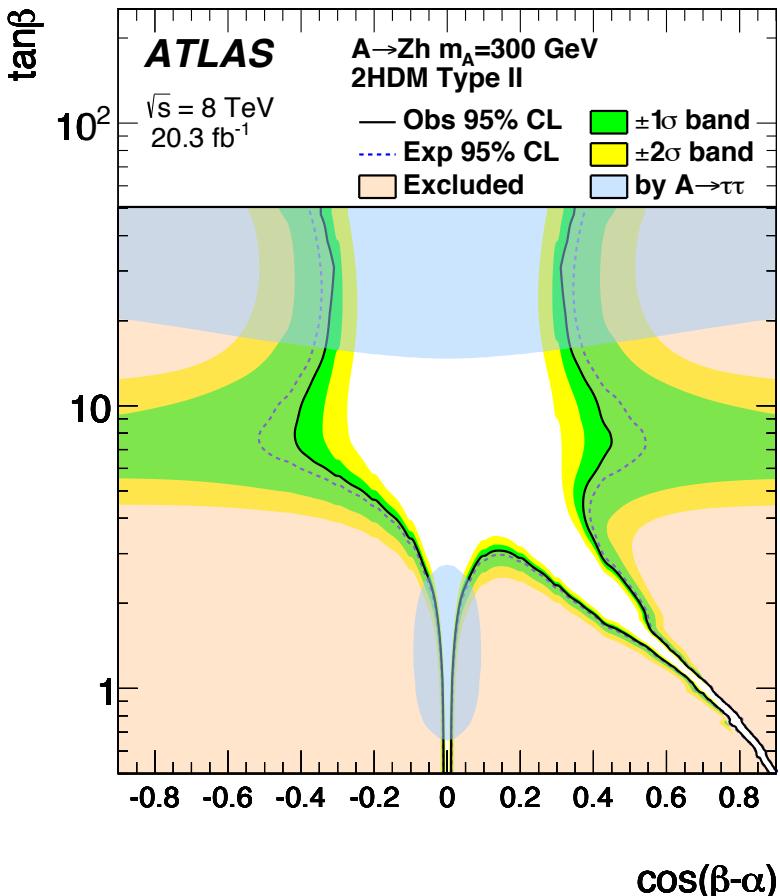
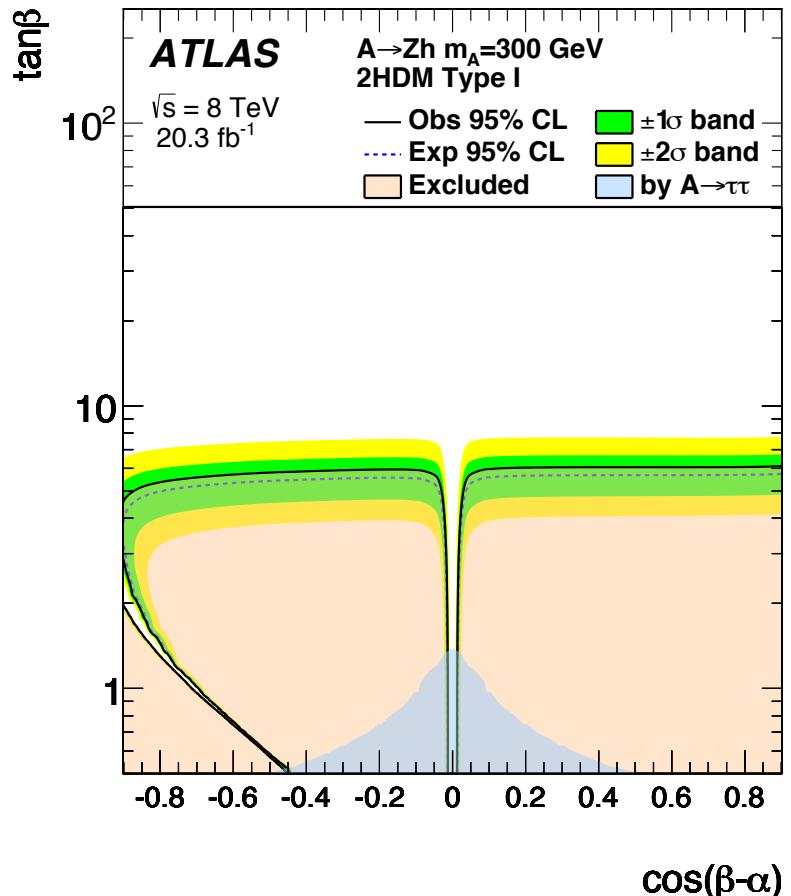
Summary

- The search for $A \rightarrow Zh$ is particularly useful to search for additional Higgs bosons in 2HDM scenarios with low $\tan(\beta)$ and m_A below $m_{t\bar{t}}$.
- The search for $A \rightarrow Zh \rightarrow ll\tau\tau$ is performed for combinations of leptonic and hadronic τ decays.
 - The final result is combined with the $A \rightarrow Zh \rightarrow ll(vv)bb$ search for interpretation in 2HDM.
- No evidence for $A \rightarrow Zh$ is observed for run-1, and limits are set on the product of the cross section times SM branching ratio, and in various 2HDM.
- The analysis was statistics-limited in run-1, so run-2 will be an interesting time for pseudoscalar A searches!



Backup

2HDM Interpretation: Type-I and Type-II



- For these limits, the $A \rightarrow Zh \rightarrow ll\tau\tau$ and $A \rightarrow Zh \rightarrow ll(vv)bb$ channels are combined, and the $A \rightarrow \tau\tau$ results are also overlaid.