Search for the pseudoscalar Higgs boson *A* of two Higgs doublet models (2HDM) with the ATLAS detector

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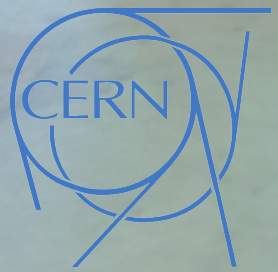
on behalf of the ATLAS collaboration

Sapienza Università di Roma

SUSY 2015,
Lake Tahoe, CA, August 23-29, 2015



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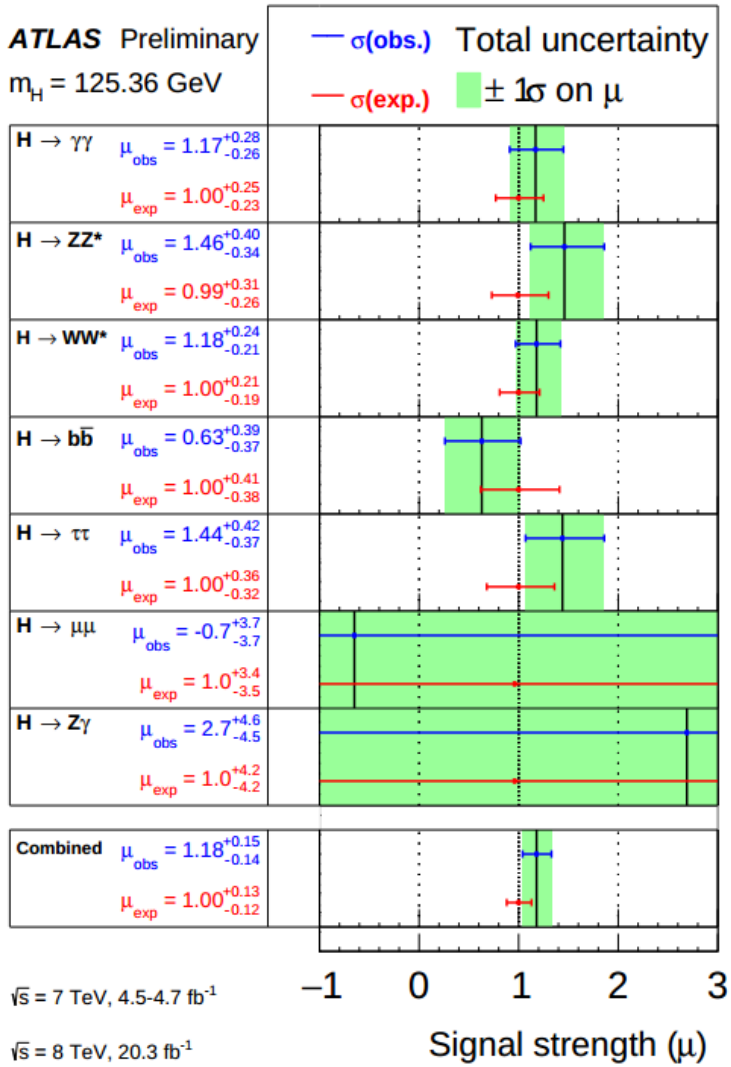
The story so far

- 2012 discovery by ATLAS & CMS of a new resonance, with properties compatible with that of SM Higgs
- No surprises so far for CP properties and couplings; uncertainties on $\sigma \times BR \approx$20-30%

Run-2

- $\sqrt{s}$: 8 TeV $\rightarrow$ 13 TeV !!!
- $O(10)$ fb^{-1} in 2015

ATLAS-CONF-2015-007



BSM searches: what to look for?

Constraints from SM Higgs

BSM interpretation of coupling measurements

Model-independent searches (SM-like)

$H \to \gamma\gamma$
$H \to WW \to e\nu\mu\nu$
$H \to WW \to \ell\nu jj$
$H \to ZZ \to 4\ell$

Specific models: 2HDM, MSSM (, ...)

Scalar (H)
$h/H \to \tau^+\tau^-$
$H \to WW, ZZ$
$H \to hh \to b\bar{b}\gamma\gamma$
$H \to hh \to b\bar{b}b\bar{b}$
$H \to b\bar{b}$

Pseudoscalar (A)
$A \to \tau^+\tau^-$
$A \to Zh \to \ell\ell b\bar{b}$
$A \to Zh \to \ell\ell\tau\tau$

Charged ($H^\pm$)
$H^\pm \to c\bar{s}$
$H^\pm \to \tau^\pm\nu$
$H \to H^\pm(+x) \to h(+x)$
$H^\pm \to tb$
$H^\pm \to W^\pm Z$

Unconventional signatures

Higgs $\to$ invisibles
Long lived particles
Lepton flavor violation

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2 Higgs Doublets Models (2HDMs)

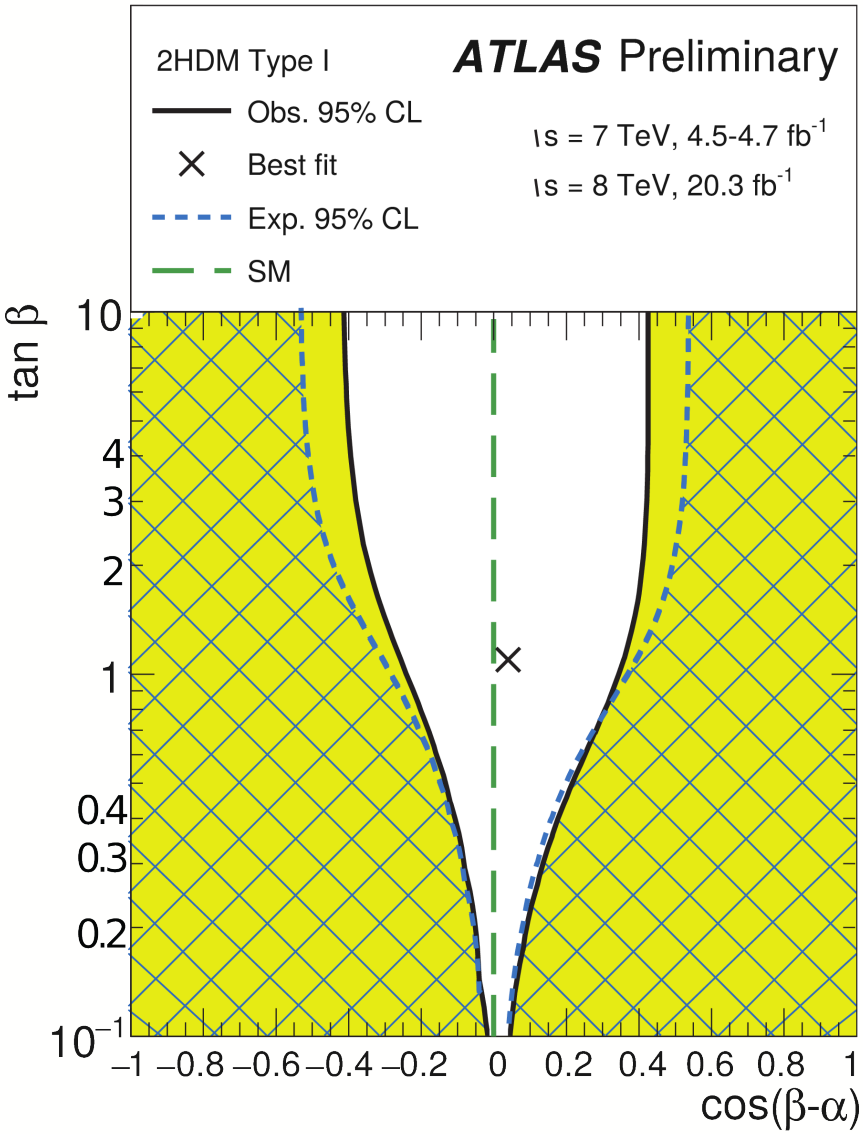
- 2 Higgs doublets, 5 particles: h and H CP-even, A CP-odd, $H^{\pm}$
  - Only one among the possible models, but an important benchmark for interpreting experimental results
- 7 free parameters (with minimum assumptions: no CP-violation in Higgs sector, no FCNC)
  - 4 masses
  - 1 soft symmetry breaking parameter
  - $\tan\beta = v_2/v_1$, ratio of the vacuum expectation values of the doublets
  - α, mixing angle between h and H. Often $\cos(\beta-\alpha)$ is used as parameter, which controls couplings (in particular $\mathcal{BR}(H \to VV)$, $\mathcal{BR}(A \to Zh) \propto \cos(\beta-\alpha)$, for $\cos(\beta-\alpha) = 0$ then $h_{2HDM} \to h_{SM}$)

- Classified depending on the structure of the couplings in 4 types
  - Type-I (Fermiophobic in the zero mixing limit)
  - Type-II (MSSM-like)
  - Lepton-specific
  - Flipped

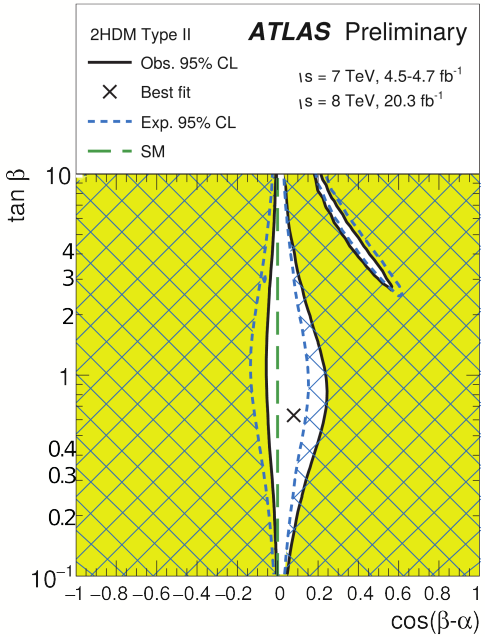
	Type I	Type II	Lepton-Specific	Flipped
k_V	$\sin(\beta-\alpha)$	$\sin(\beta-\alpha)$	$\sin(\beta-\alpha)$	$\sin(\beta-\alpha)$
k_u	$\cos(\alpha)/\sin(\beta)$	$\cos(\alpha)/\sin(\beta)$	$\cos(\alpha)/\sin(\beta)$	$\cos(\alpha)/\sin(\beta)$
k_d	$\cos(\alpha)/\sin(\beta)$	$-\sin(\alpha)/\cos(\beta)$	$\cos(\alpha)/\sin(\beta)$	$-\sin(\alpha)/\cos(\beta)$
k_ℓ	$\cos(\alpha)/\sin(\beta)$	$-\sin(\alpha)/\cos(\beta)$	$-\sin(\alpha)/\cos(\beta)$	$\cos(\alpha)/\sin(\beta)$

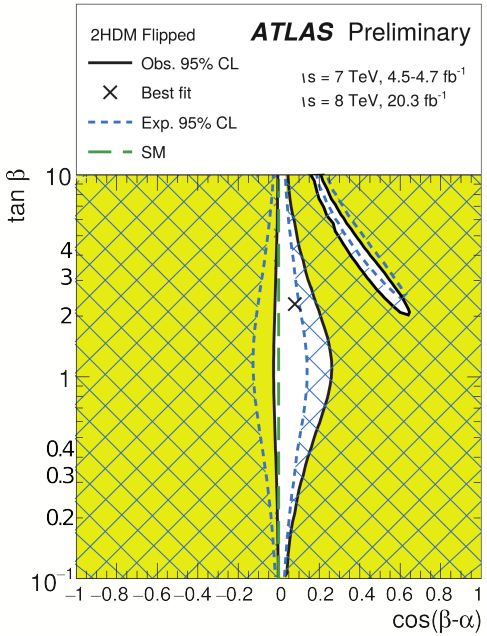
- At tree level the SUSY Higgs sector is as in Type-II
- Model independent parametrization of the Higgs sector for MSSM: hMSSM, see *Djouadi et al. 1502.05653*

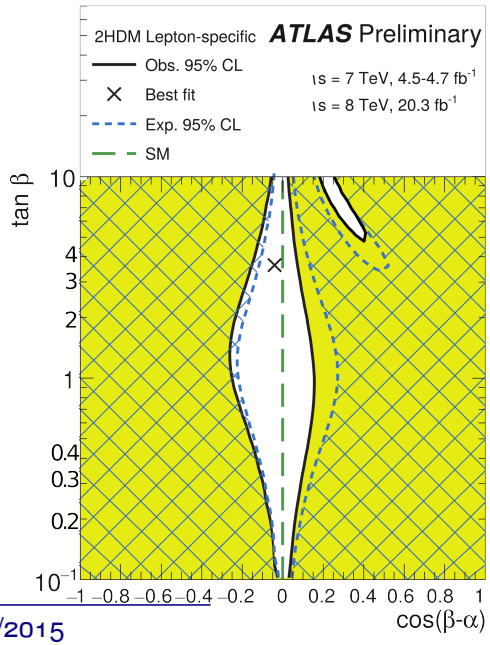
Indirect constraints on 2HDMs



Plots from HIGG-2015-03



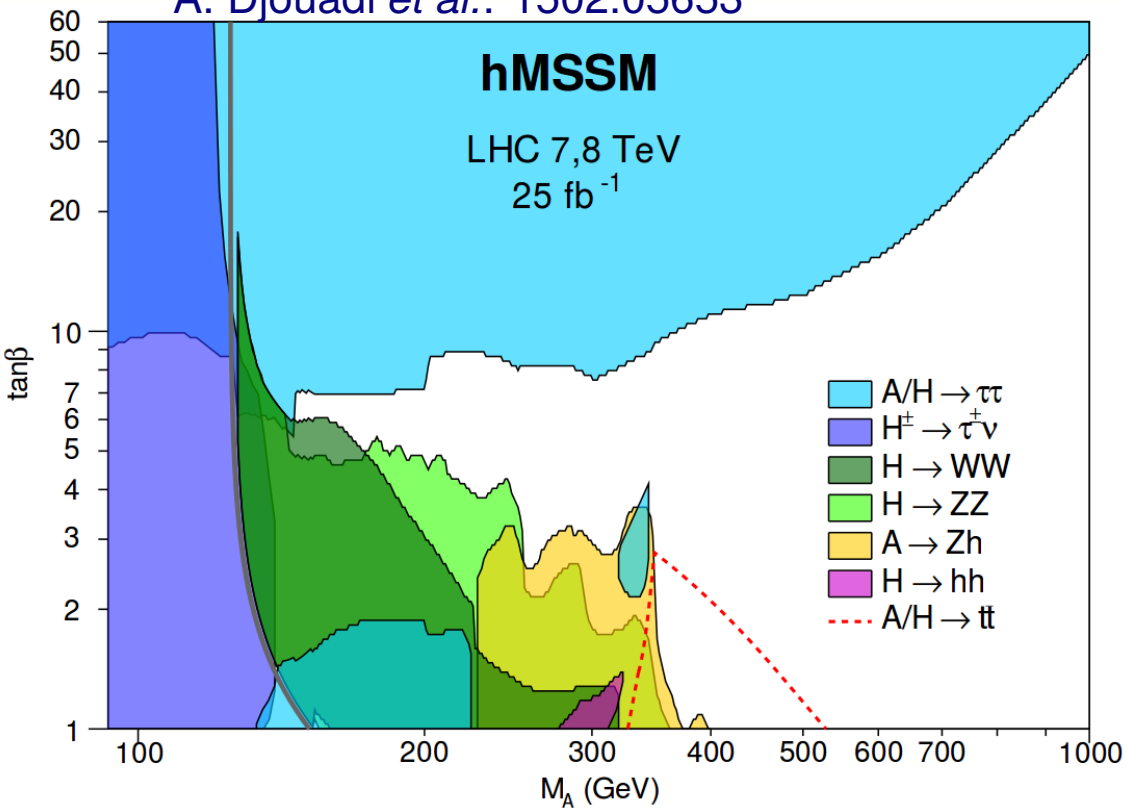


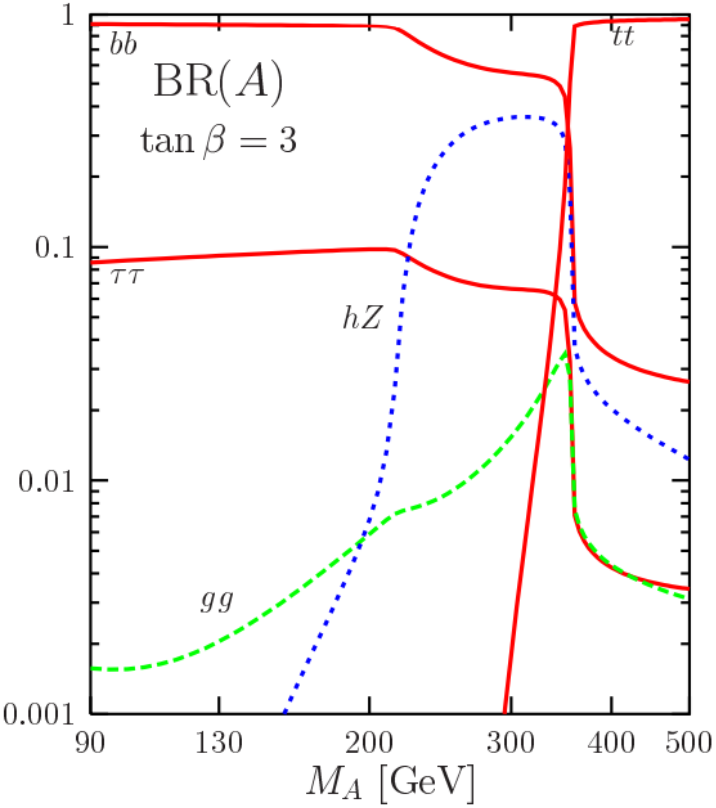


2HDM parameter space is significantly constrained by h^{SM} couplings measurements

2HDMs phenomenology

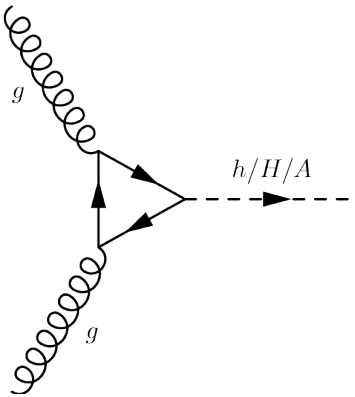
A. Djouadi *et al.*: 1502.05653





- For low tan β and $m_X < 2m_{top}$ most sensitive channels:
  - $H \to hh$, $H \to ZZ$, $H \to WW$, $H \to \tau\tau$
  - $A \to Zh$
- For high tan β both are completely dominated by $b\bar{b}$ (search with associated production) and $\tau\tau$

Search for $h/H/A \to \tau\tau$



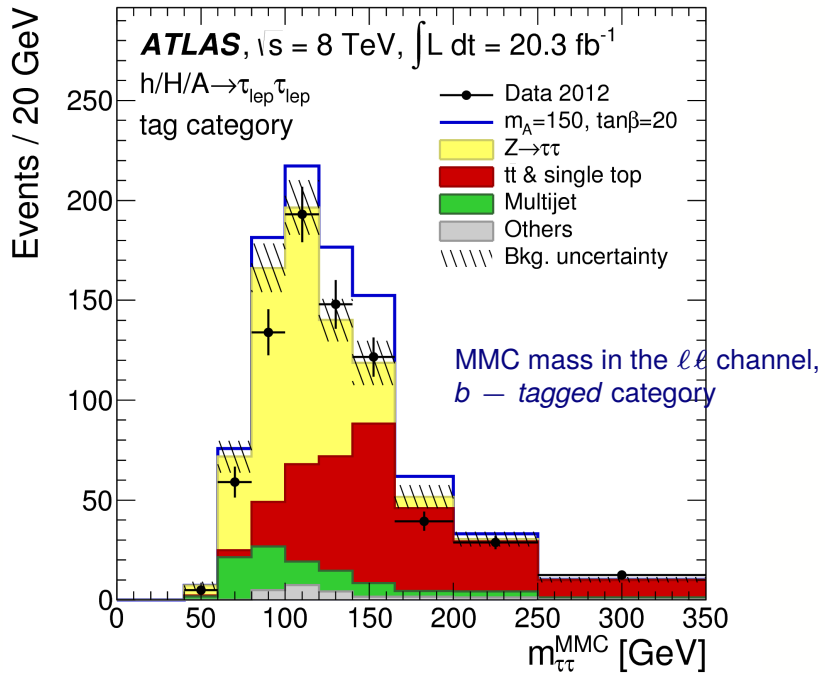
- Model-independent search for scalar resonances
- Key search for high-tan β MSSM
- Search channels:
  - $\tau\tau \to \ell\ell$(+*neutrinos*), low mass
  - $\tau\tau \to \ell$ + *hadrons*(+*neutrinos*), low/high mass
  - $\tau\tau \to$ *hadrons*(+*neutrinos*), high mass

Neutrinos in the final state, thus complete kinematics reconstruction is not possible

Missing Mass Calculator

Missing Mass Calculator used for the reconstruction (MMC, NIM A 654 (2011) 481–489):

- E_T^{miss} and 4-momenta of all visible objects are used
- $m_{\tau\tau}$ most probable value is calculated with a likelihood



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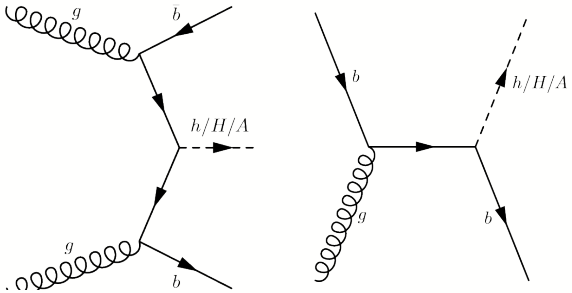
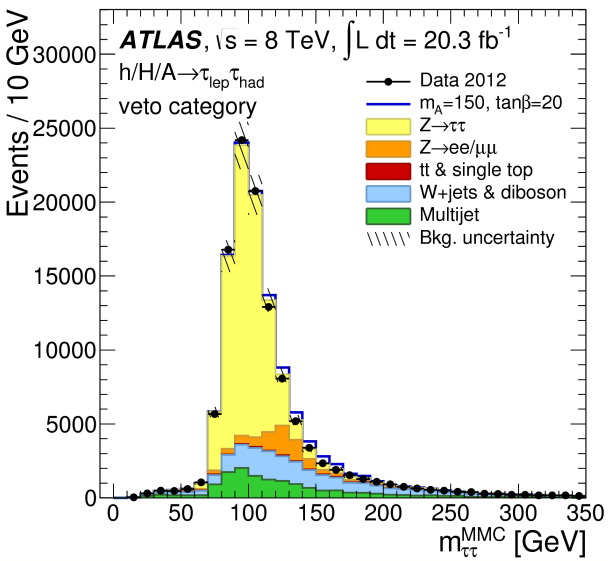
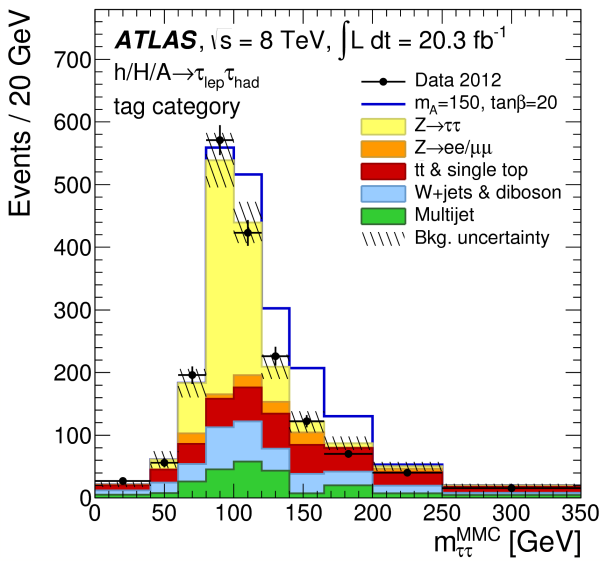
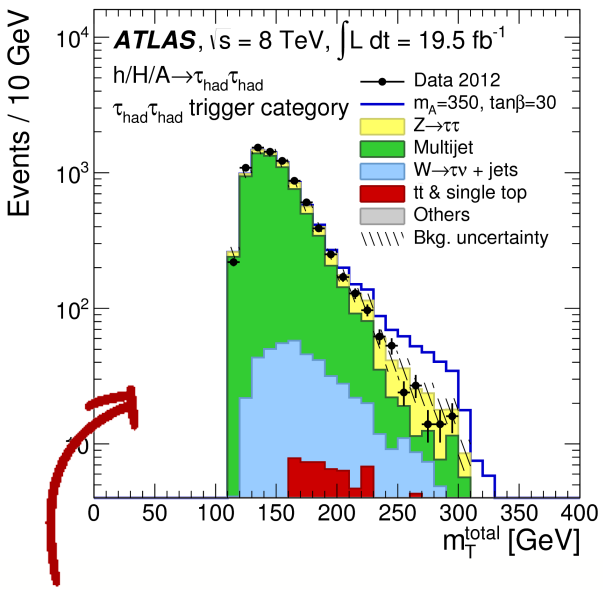
Search for $h/H/A \to \tau\tau$



- *b – vetoed* and *b – tagged* categories in search region $m_{H/A} < 200$ GeV
- Improved sensitivity for *gg* and *b*-associated production modes







Dedicated kinematic requirements in different subregions for different background rejection:

- Irreducible $Z \to \tau^+\tau^-$ background modeled from $Z \to \mu^+\mu^-$ data sample; others from MC.

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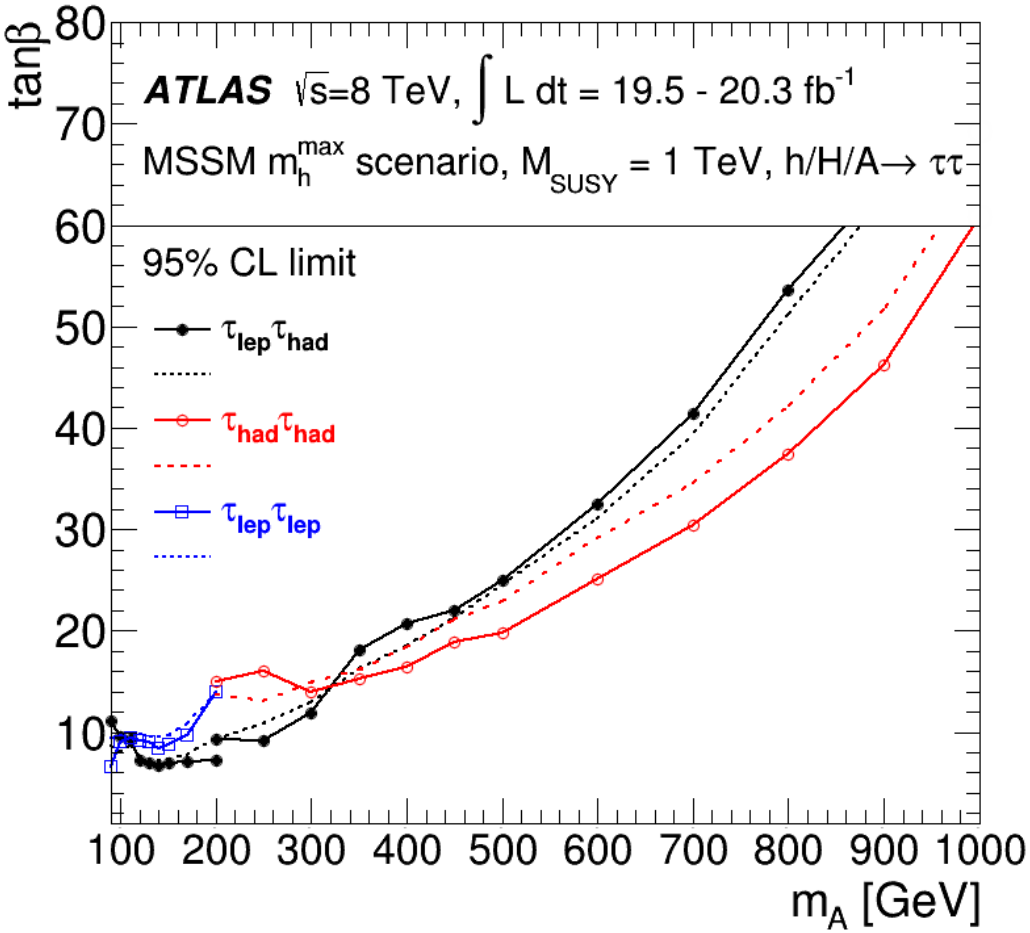
Trasverse mass in $\tau_h\tau_h$ final state show better QCD multi-jet background rejection:

$$\sqrt{m_T^2(\tau_1,\tau_2) + m_T^2(\tau_1, E_T^{miss}) + m_T^2(\tau_2, E_T^{miss})}$$

Search for $h/H/A \to \tau\tau$



- High tan β 2HDMs significanlty constrained for $m_A \ll 1$ TeV
- High tan β, $m_A \approx 1$ TeV region is a target for very early Run-2 measurements
- Low tan β, $m_A \approx 300$ GeV region need to be explored by other searches

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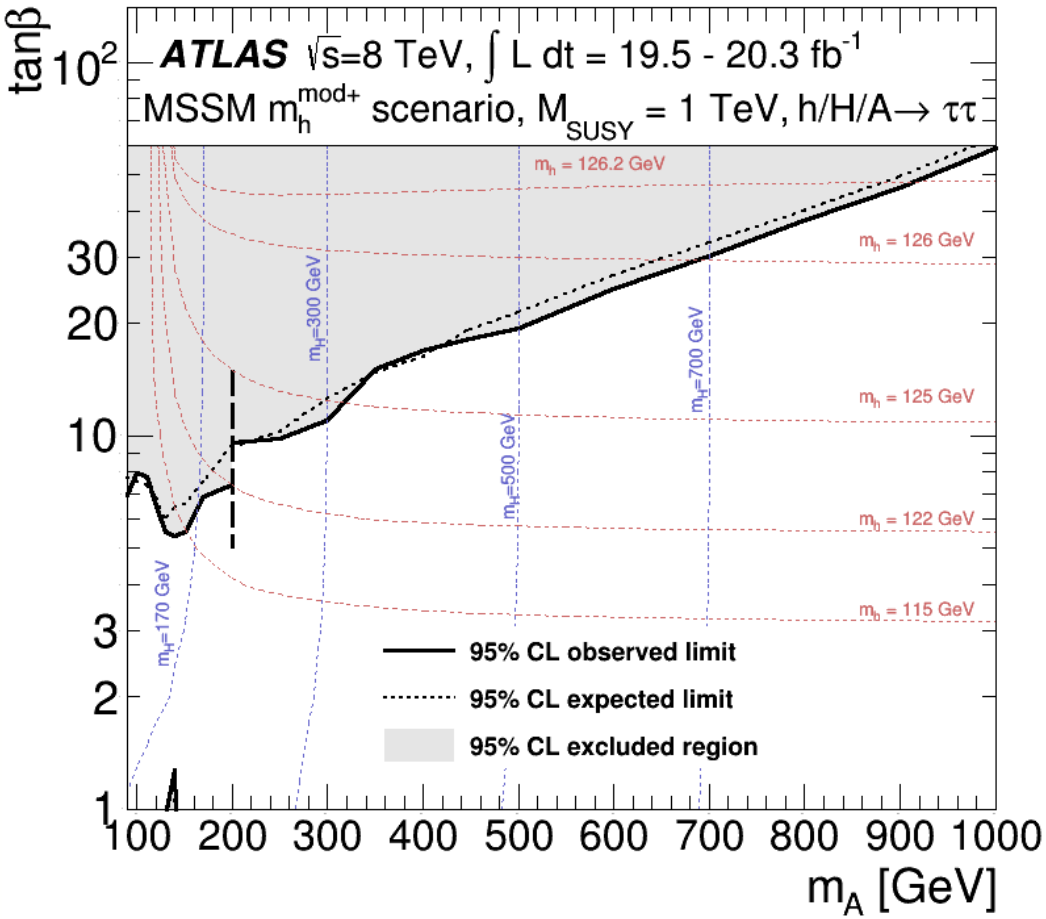
Search for $h/H/A \to \tau\tau$



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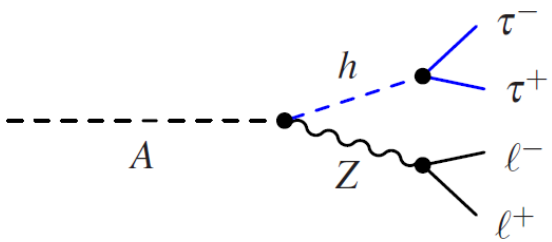
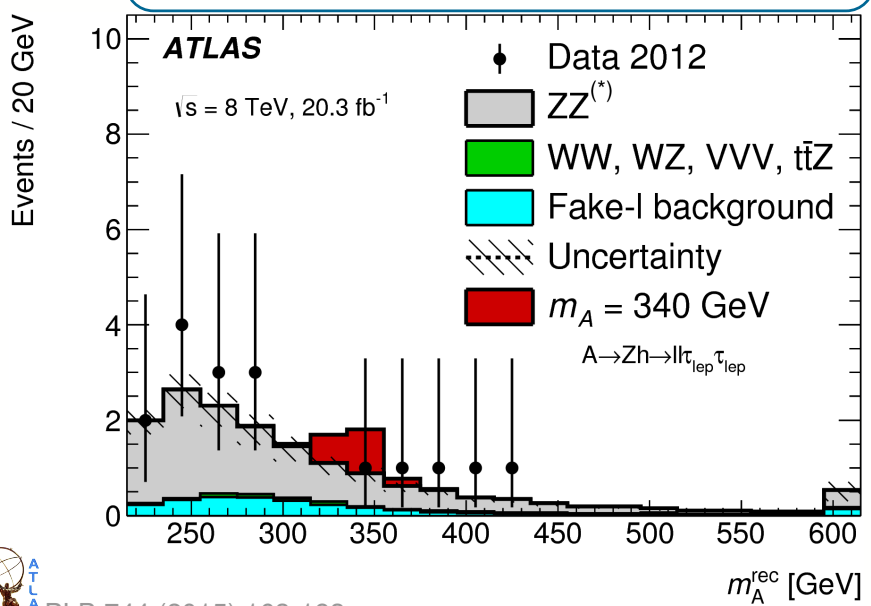
Search for $A \to Zh$



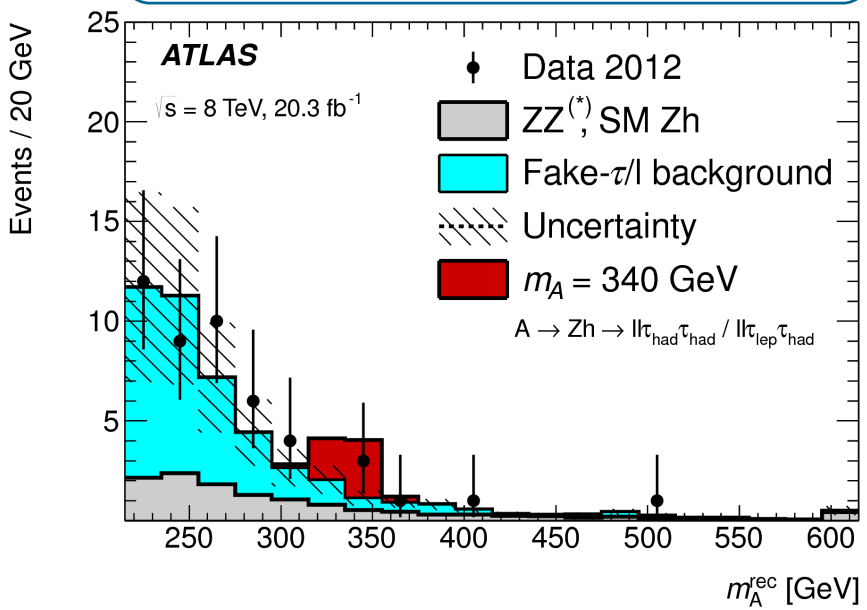
$A \to Zh \to \ell\ell\tau\tau$

- $\tau_\ell\tau_\ell$, $\tau_\ell\tau_{had}$, $\tau_{had}\tau_{had}$ reconstructed
- $\tau\tau$ decay reconstructed with MMC, improving $m_{\tau^+\tau^-\ell\ell}$
- Constraints to $m_{\ell\ell}$ and $m_{\tau\tau}$:
  $m_A^{rec} = m_{\ell\ell\tau\tau} - m_{\ell\ell} - m_{\tau\tau} + m_Z + m_h$
- $\sigma(m_A)/m_A \approx$3-5%

Background modeled from simulation for $\tau_\ell\tau_\ell$.



Fake τ/ℓ background modeled from data CRs.



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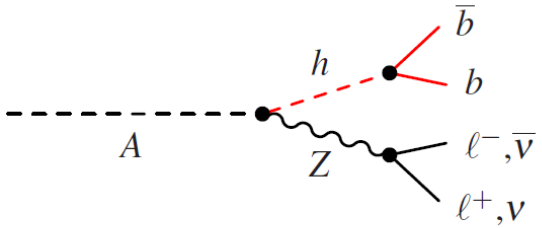
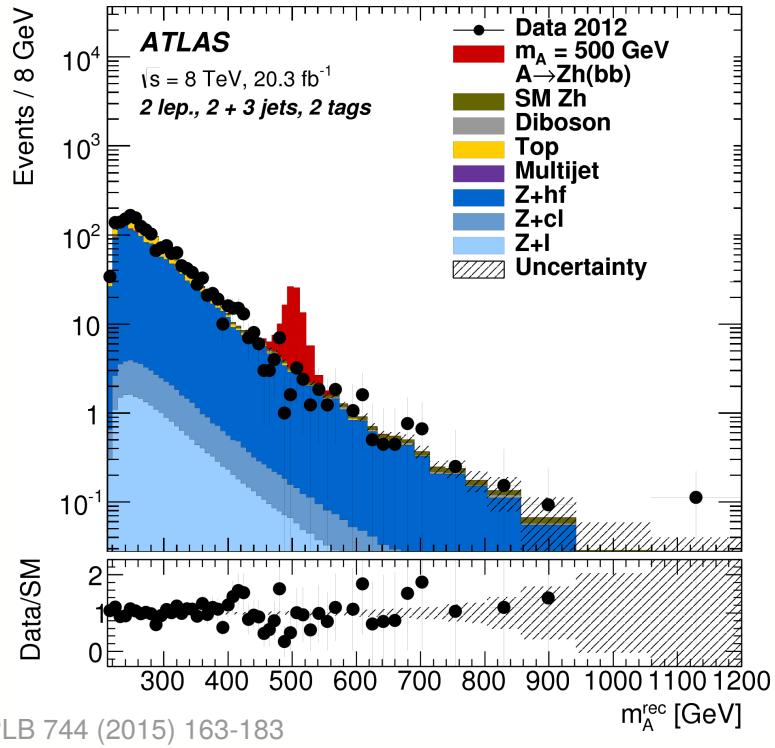
Search for $A \to Zh$

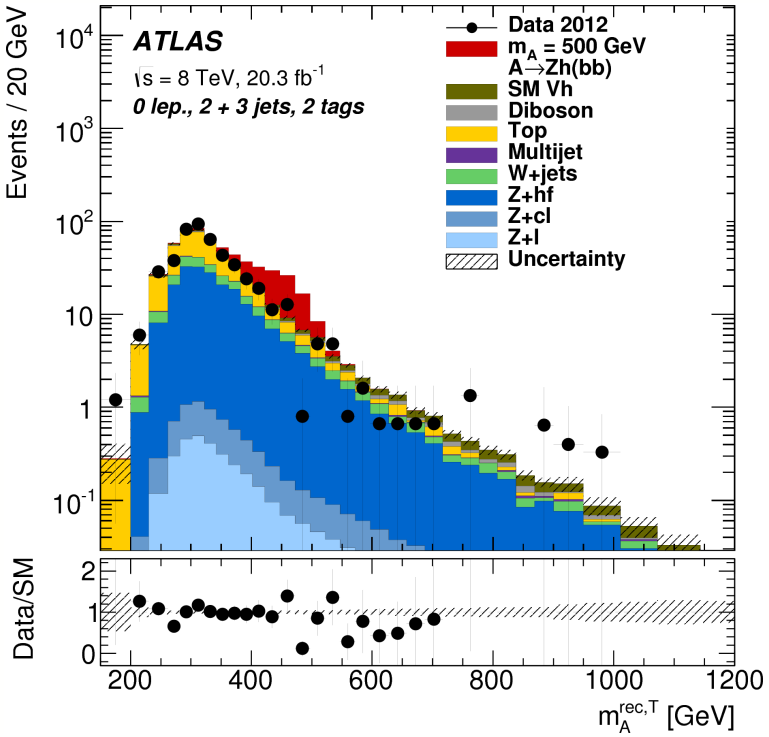


$$A \to Zh \to (\ell\ell/\nu\nu)b\bar{b}$$

- $\ell\ell$: 2 $b-$jets selected, >2 vetoed, m_{bb} constrained to m_h and $\in$ [105,145] GeV range.
  $\sigma(m_A)/m_A \approx$ 2-3%
- $\nu\nu$: discriminant variable
  $m_A^{rec} = \sqrt{E_T^{bb} + E_T^{miss})^2 + (\vec{p}_T^{bb} + \vec{E}_T^{miss})^2}$

Multijet background from data *anti-isolated* samples, all others from MC simulations.





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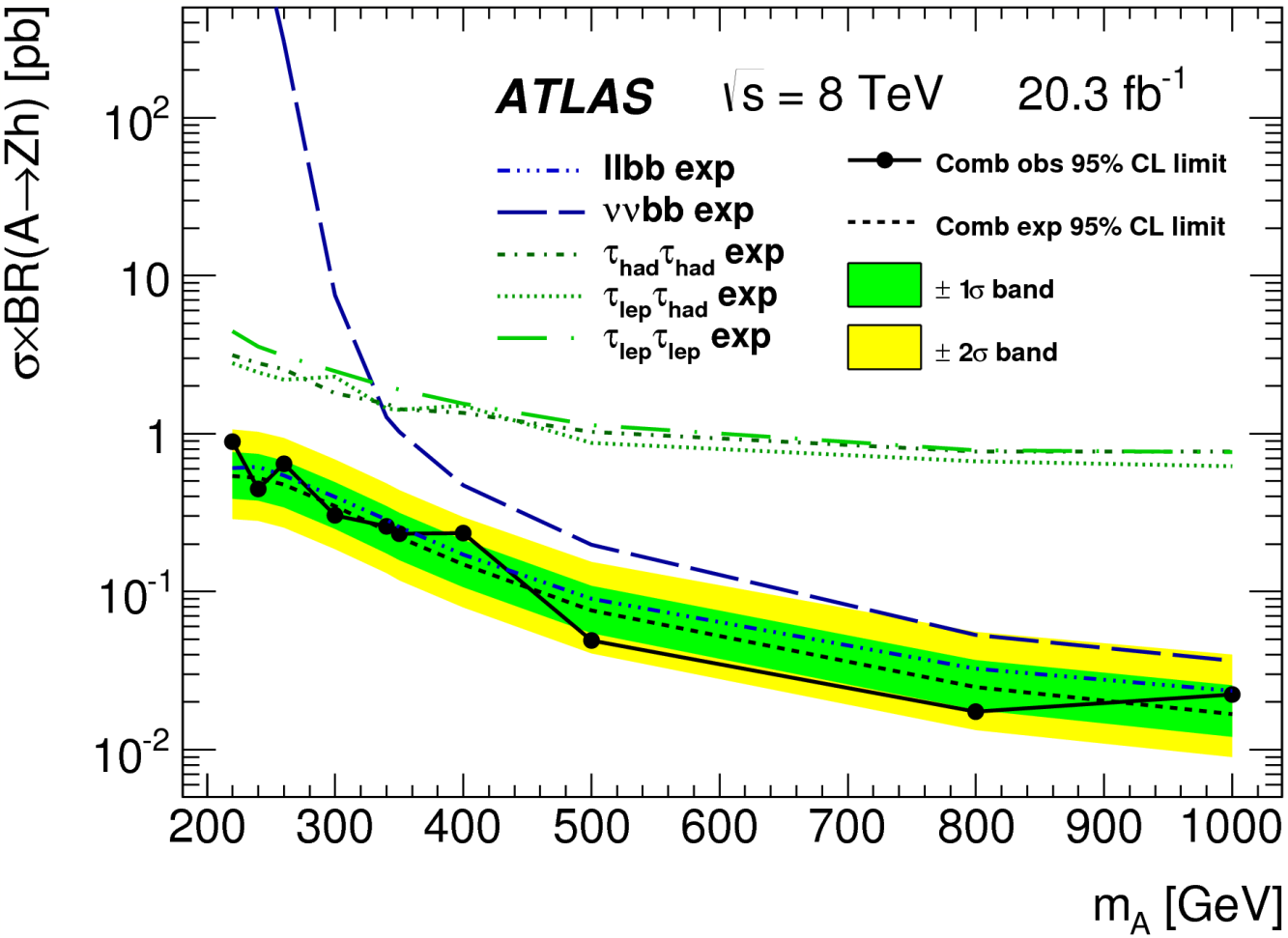
From a fit to the reconstructed m_A distributions in the different channels, upper limit on the production cross section.



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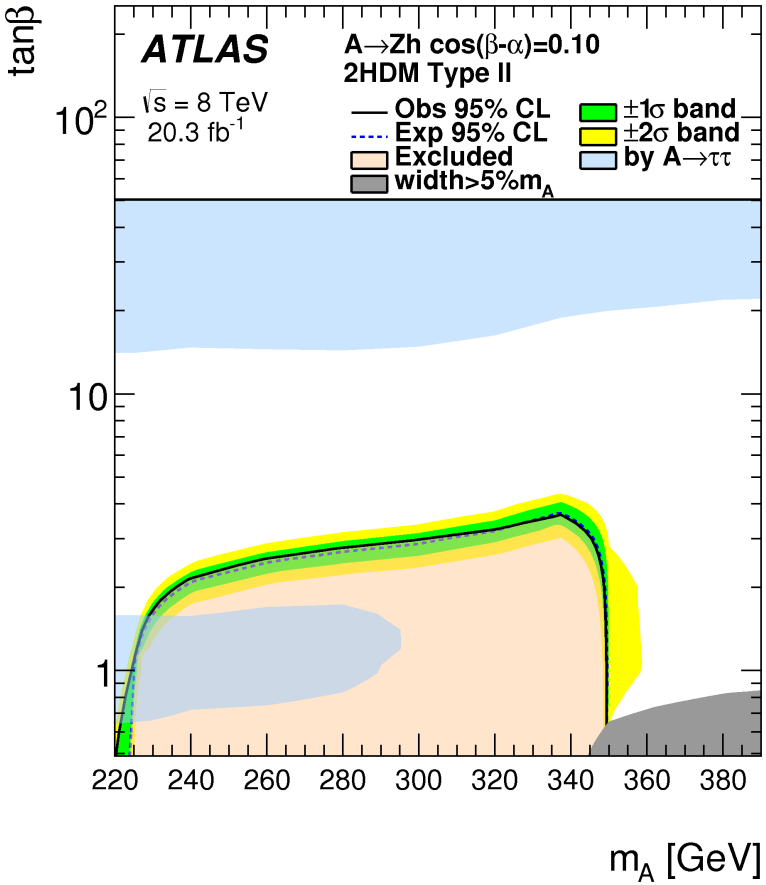
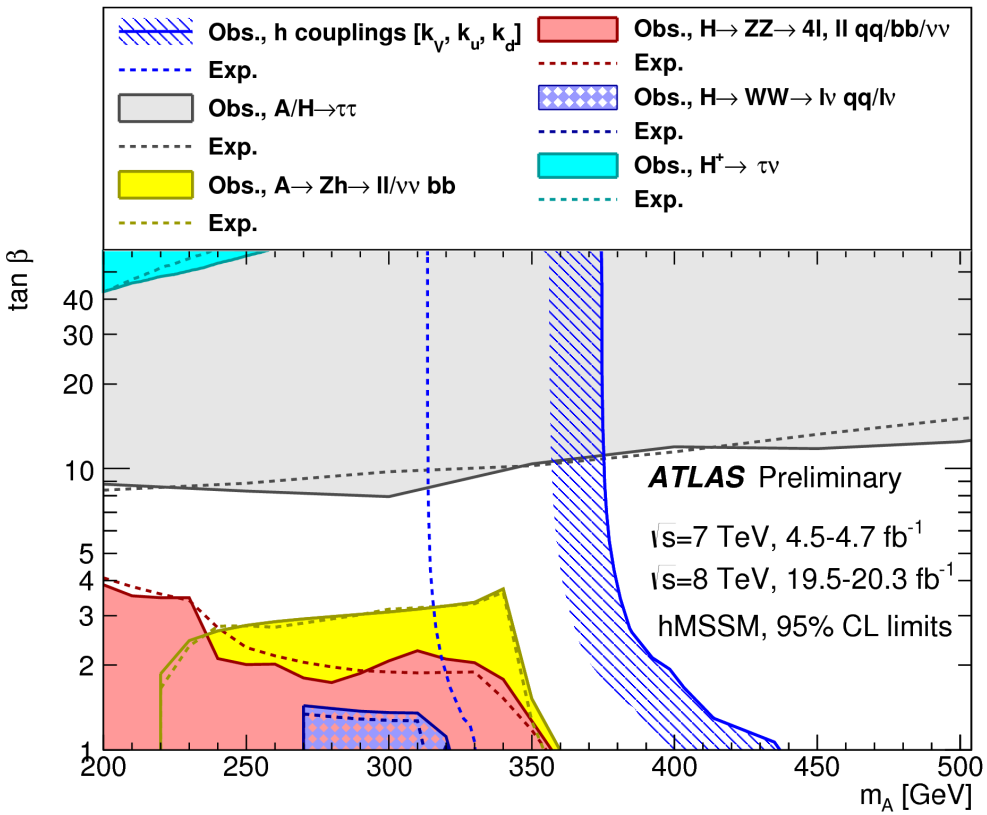
$A \to Zh$ SEARCH RESULT

The result is interpreted in the parameter space of 2HDM benchmarks



and compared with complementary searches



Sensitive up to tan β ≈5-7, complementary to $A \to \tau\tau$

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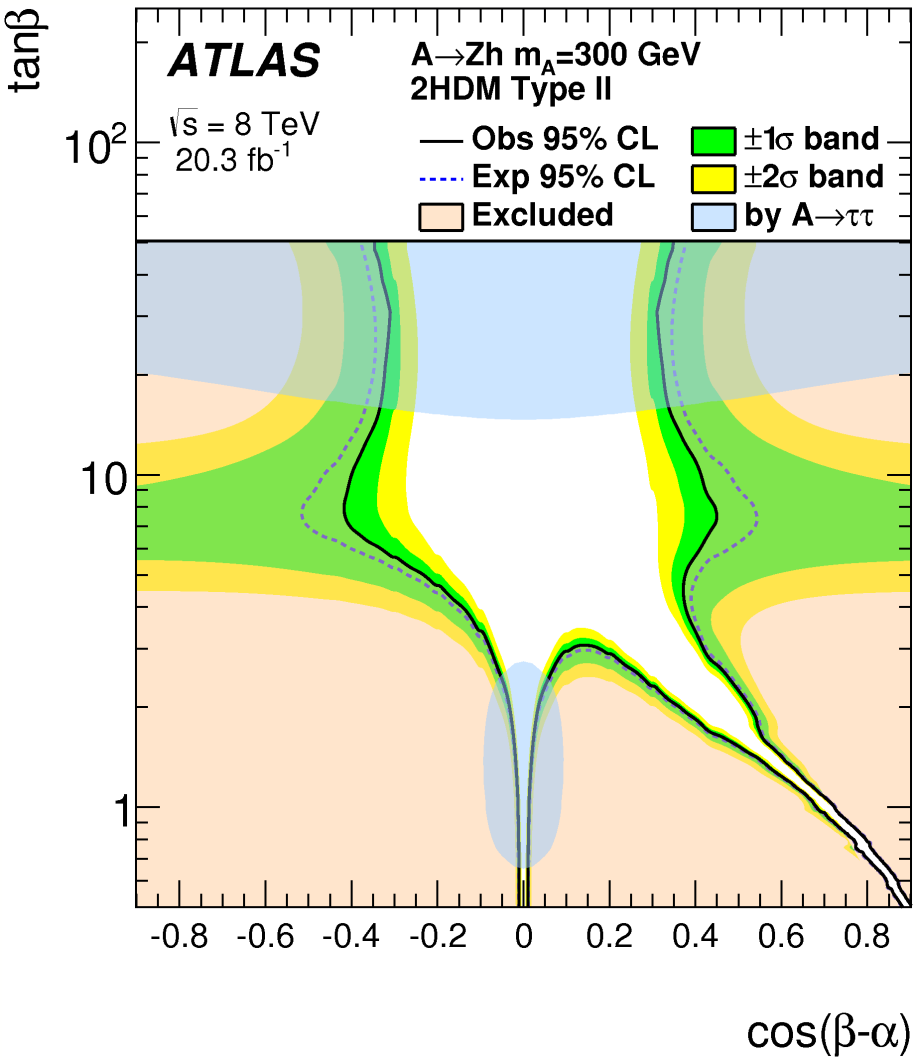
arXiv:1507.05930

Comparison with other results

$A \to Zh$ and $A \to \tau\tau$, m_A= 300 GeV



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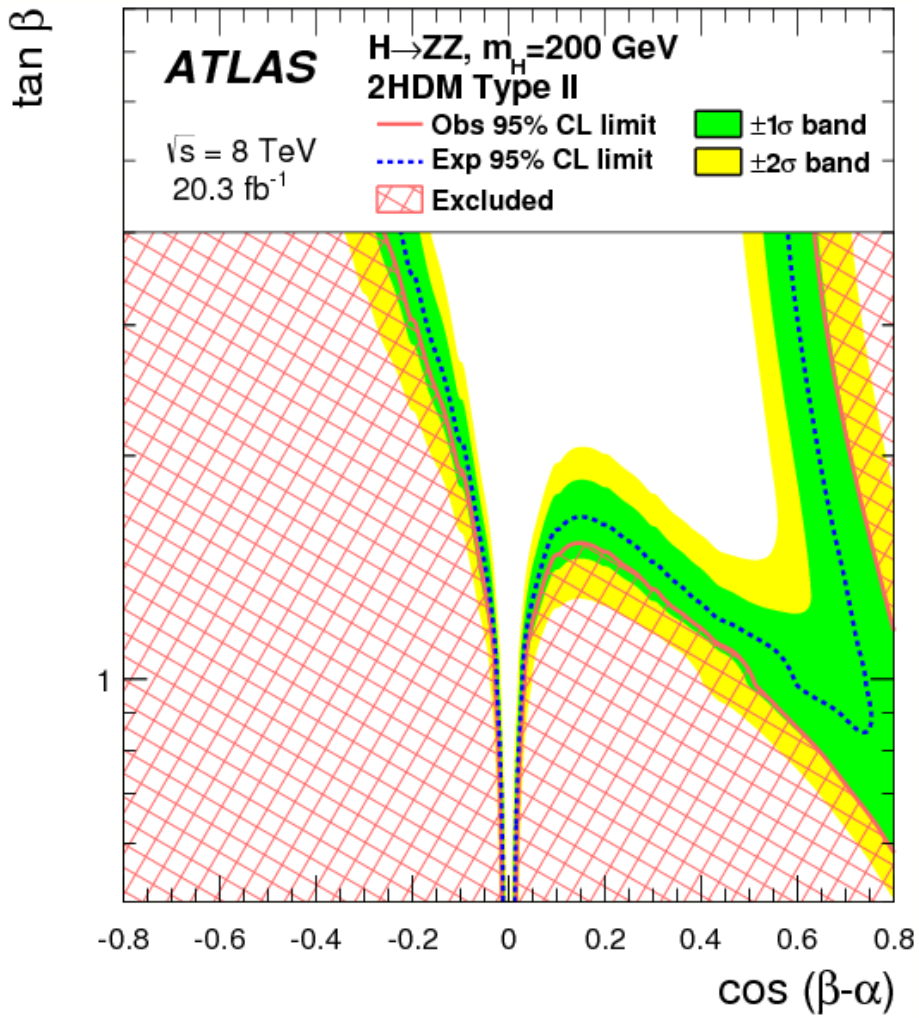
$H \to ZZ$, m_A= 200 GeV



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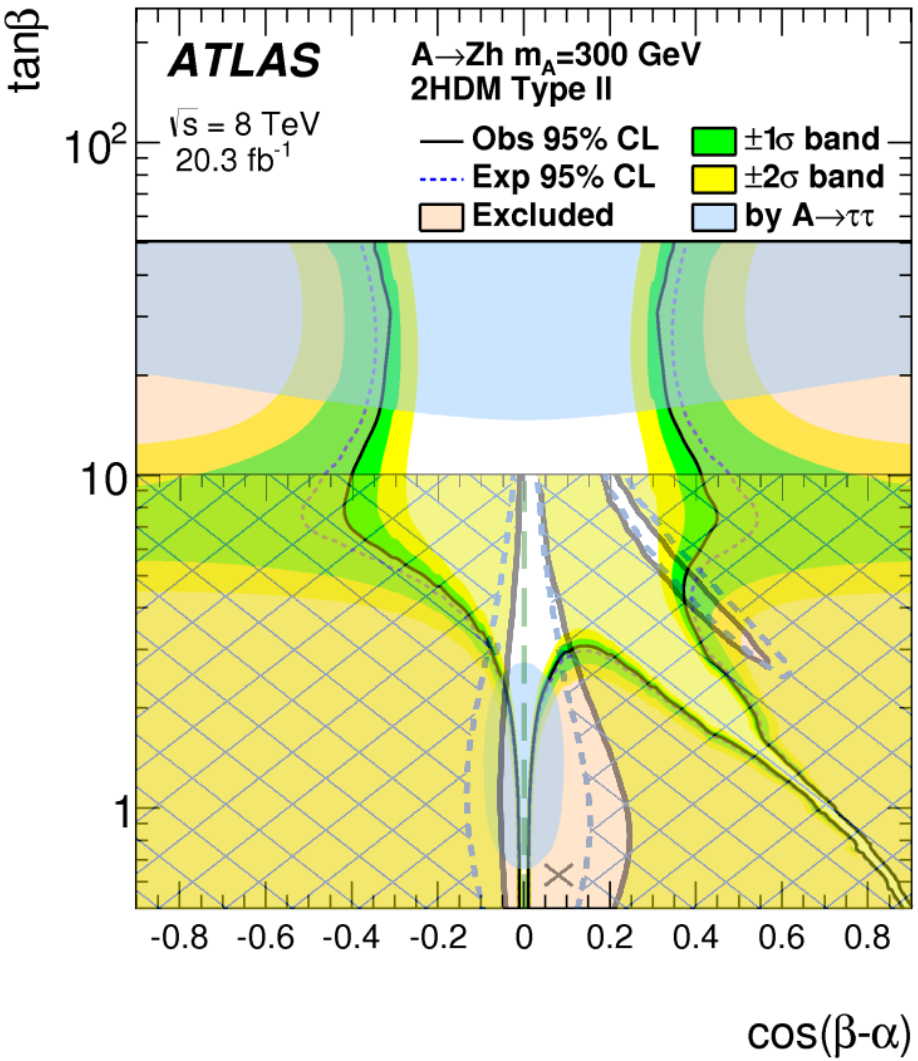

- Here shown a "quick-and-dirty" overlay of the exclusion plot in the tan β vs cos $(\beta - \alpha)$ space of $A \to Zh$ and $A \to \tau\tau$ searches, assuming m_A =300 GeV, and the one obatined by indirect constraints produced measuring h couplings, for 2HDM Type II models

2HDMs with $m_A \approx 300$ GeV are significantly constrained

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Conclusions

- ATLAS is carrying out BSM Higgs searches to explore all possible models, **pseudoscalar A searches presented here:**
  - $A \to \tau\tau$
  - $A \to Zh\ell\ell\tau\tau$, $\ell\ell b\bar{b}$, $\nu\nu b\bar{b}$
- No BSM physics discovery, but Run II just started:
  - looking forward for upcoming data!
- 8 TeV $\to$ 13 TeV: high priority to model independent resonance searches for early Run-2
- Early BSM searches similar to Run I, will be interesting already with very few fb^{-1}

Thanks!

BACKUP