Ricerca di bosoni di Higgs oltre il Modello Standard con l'esperimento ATLAS al Large Hadron Collider

M. Bauce

Sapienza Università di Roma

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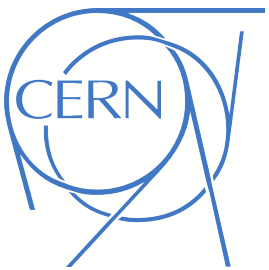


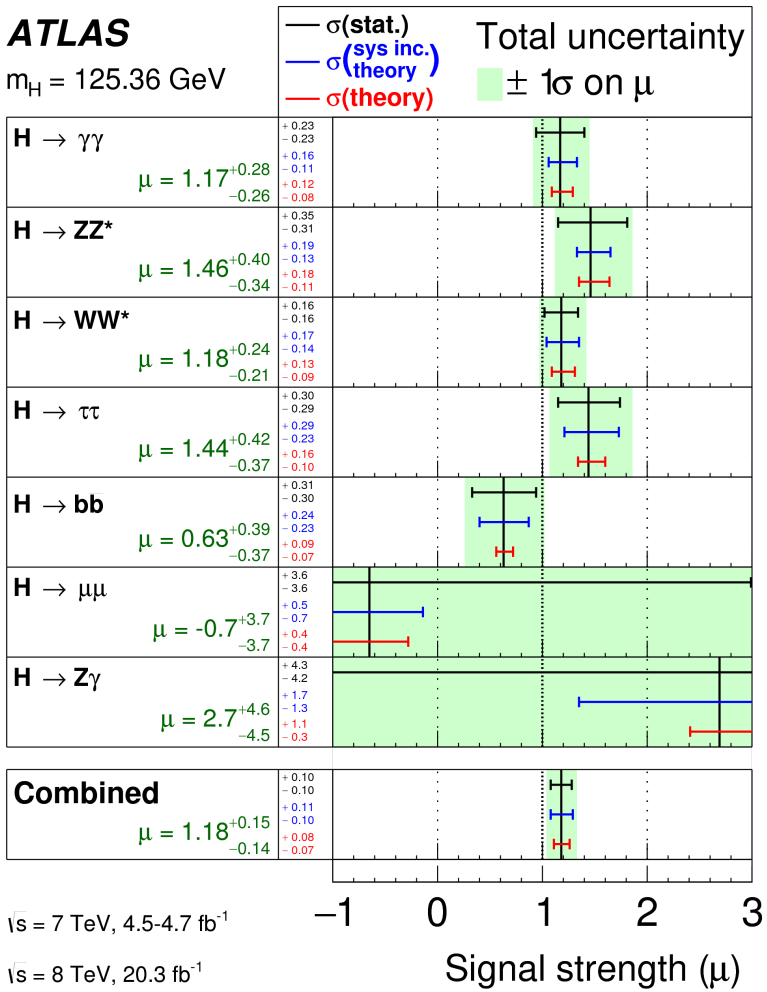
Introduction

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 !!!
- $\mathcal{O}(5)$ fb^{-1} in 2015



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

2 Higgs Doublets Models (2HDMs)

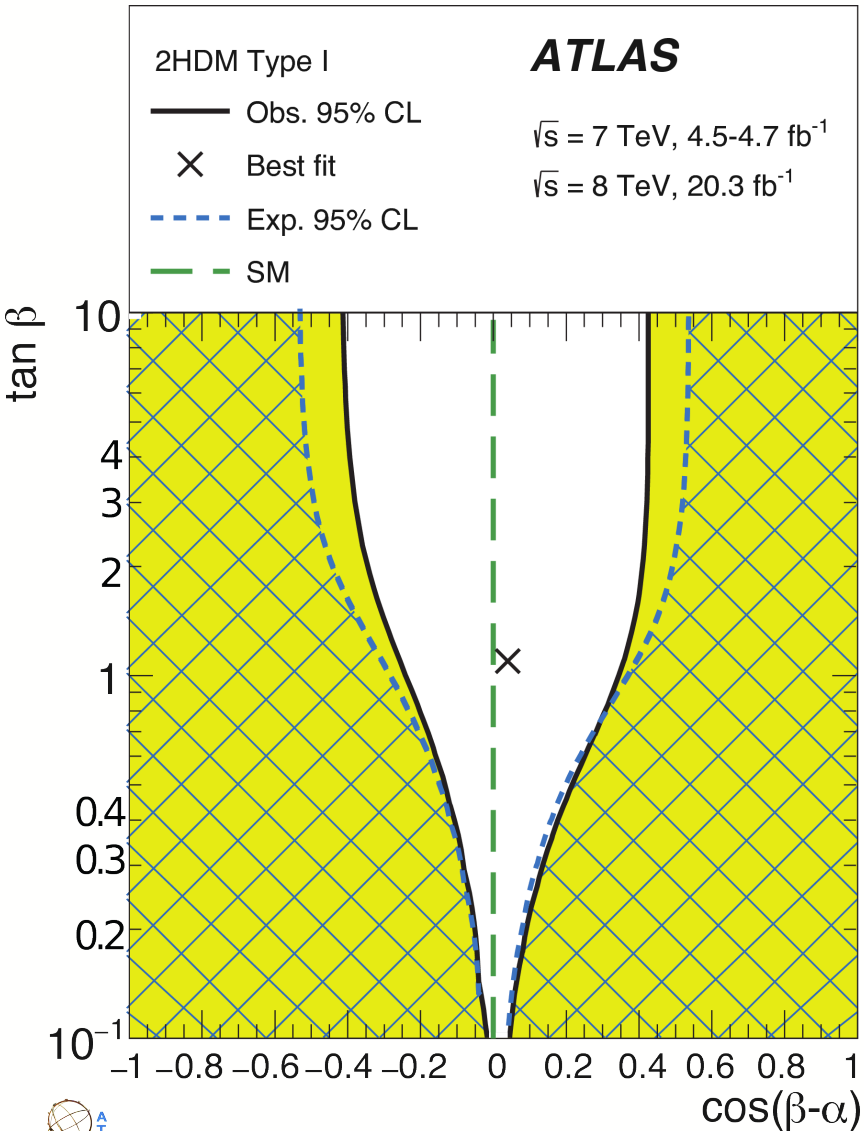
- 2 Higgs doublets, 5 particles: h and H CP-even, A CP-odd, $H^{\pm}$
  - Only one among the possible models, but an important benchmark for interpreting experimental results
- 7 free parameters (with minimum assumptions: no CP-violation in Higgs sector, no FCNC)
  - 4 masses
  - 1 soft symmetry breaking 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 $h_{2HDM} \to h_{SM}$)

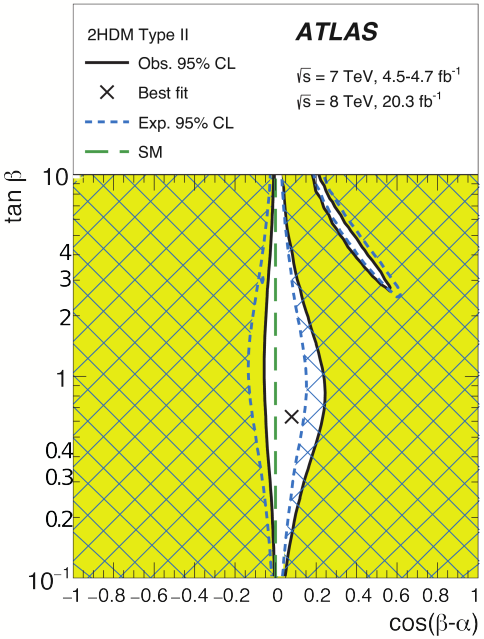
- Classified depending on the structure of the couplings in 4 types
  - Type-I (Fermiophobic in the zero mixing limit)
  - Type-II (MSSM-like)
  - Lepton-specific
  - Flipped

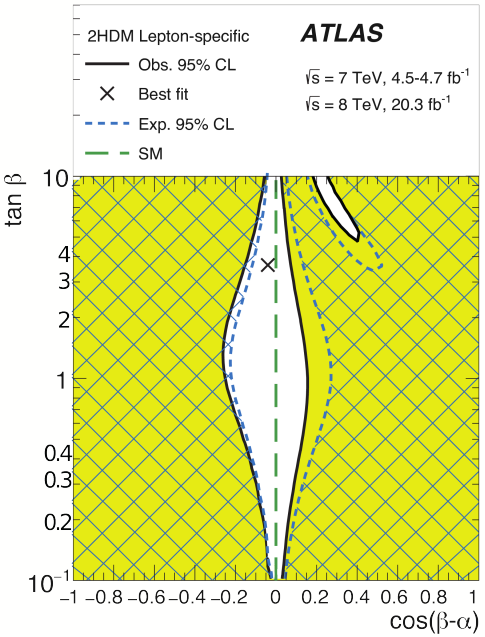
	Type I	Type II	Lepton-Specific	Flipped
k_V	$\sin(\beta-\alpha)$	$\sin(\beta-\alpha)$	$\sin(\beta-\alpha)$	$\sin(\beta-\alpha)$
k_u	$\cos(\alpha)/\sin(\beta)$	$\cos(\alpha)/\sin(\beta)$	$\cos(\alpha)/\sin(\beta)$	$\cos(\alpha)/\sin(\beta)$
k_d	$\cos(\alpha)/\sin(\beta)$	$-\sin(\alpha)/\cos(\beta)$	$\cos(\alpha)/\sin(\beta)$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

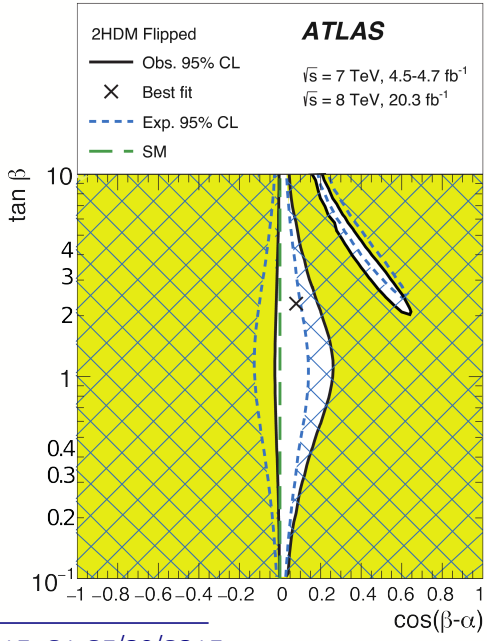
- At tree level the SUSY Higgs sector is as in Type-II
- Model independent parametrization of the Higgs sector for MSSM: hMSSM, see *Djouadi et al. 1502.05653*

Constraints on new Phenomena





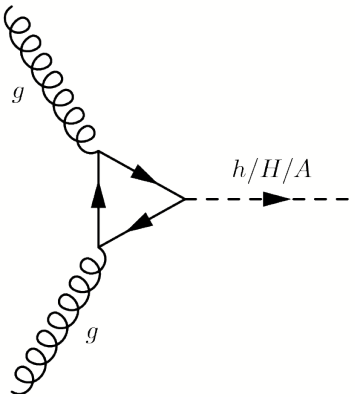




2HDM parameter space is significantly constrained by h^{SM} couplings measurements

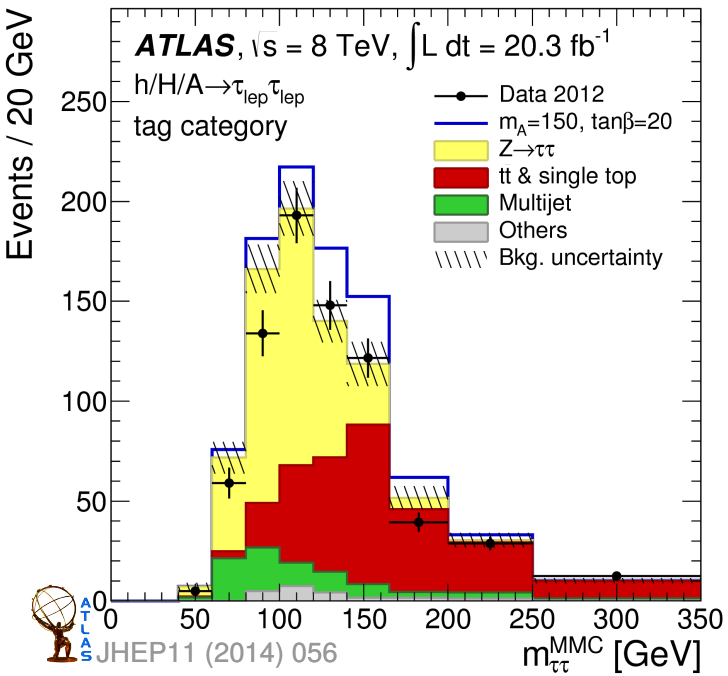
arXiv:1509.00672

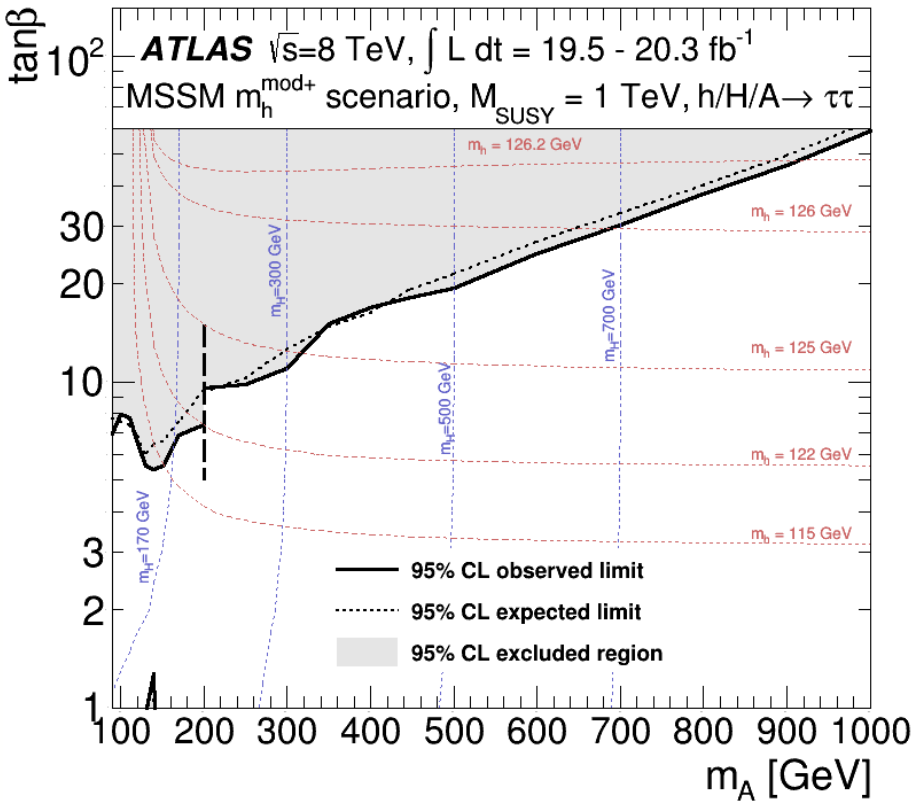
Search for $h/H/A \to \tau\tau$



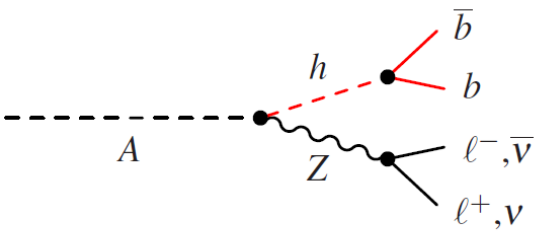
- Model-independent search for scalar resonances
- Key search for high-tan β MSSM
- Search channels:
  - $\tau\tau \to \ell\ell$(+*neutrinos*), low mass
  - $\tau\tau \to \ell$ + *hadrons*(+*neutrinos*), low/high mass
  - $\tau\tau \to$ *hadrons*(+*neutrinos*), high mass

Missing Mass Calculator: likelihood for $\tau\tau$ mass reconstruction



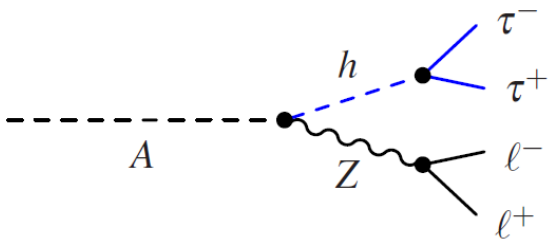


Search for $A \to Zh$



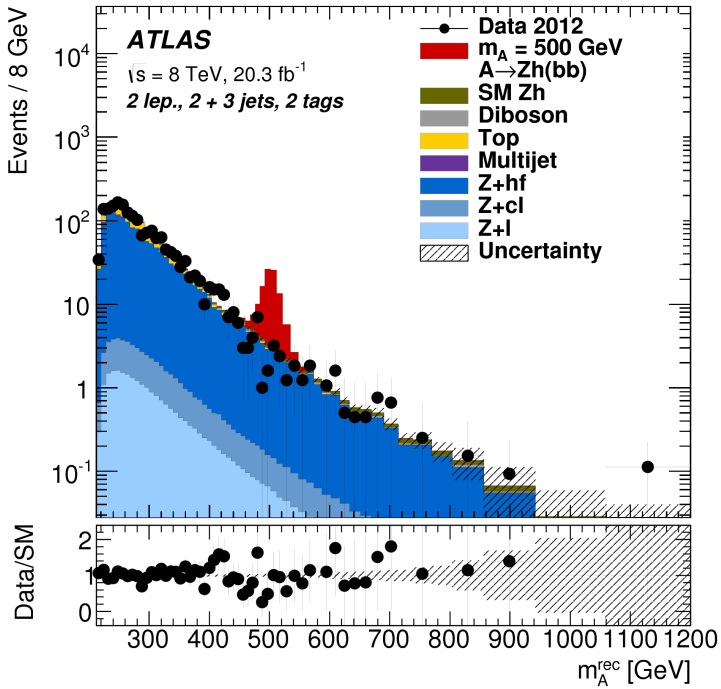
- $\ell\ell$: 2 $b-$jets selected, >2 vetoed, $105 < m_{bb} < 145$ GeV. $\sigma(m_A)/m_A \approx$ 2-3%
- $\nu\nu$: discriminant variable

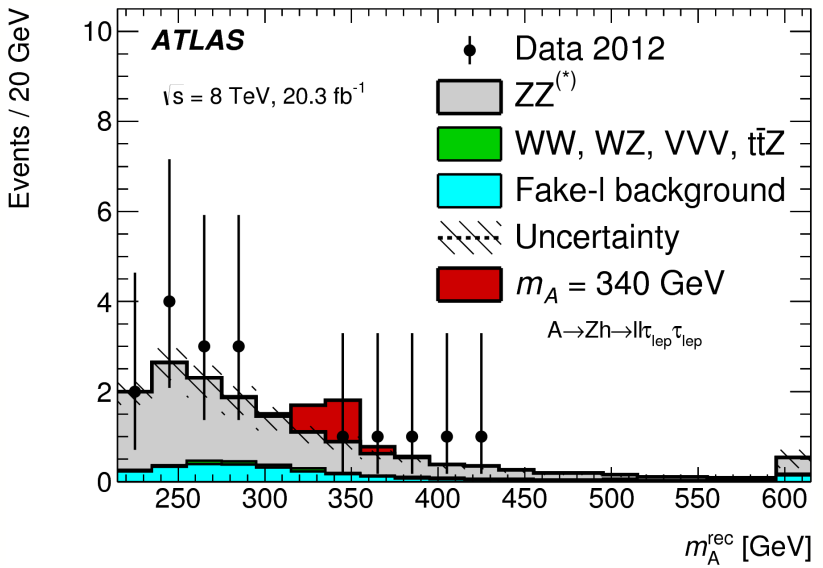
$$m_A^{rec} = \sqrt{E_T^{bb} + E_T^{miss})^2 + (\vec{p}_T^{bb} + \vec{E}_T^{miss})^2}$$



- $\tau\tau$ decay reconstructed with MMC
- 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%

PLB 744 (2015) 163-183

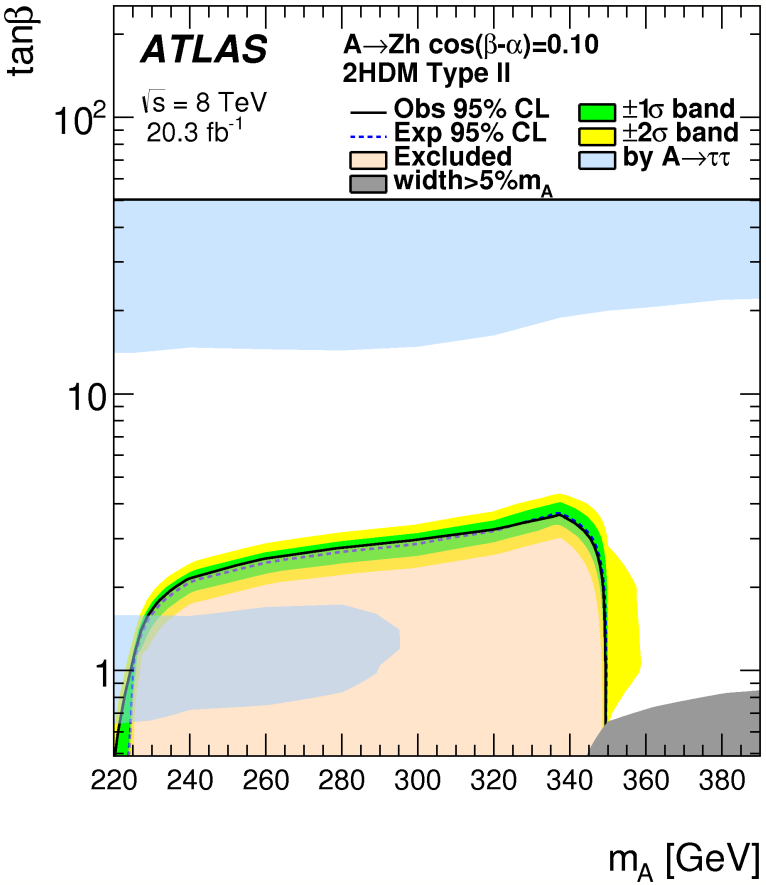


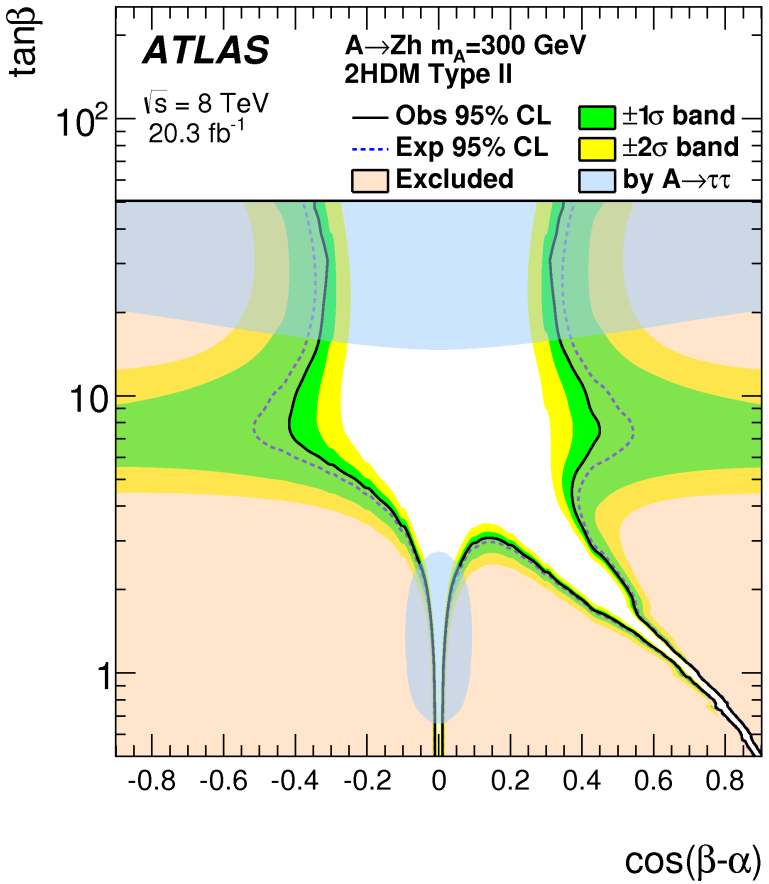


Search $A \to Zh$

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

and compared with complementary searches

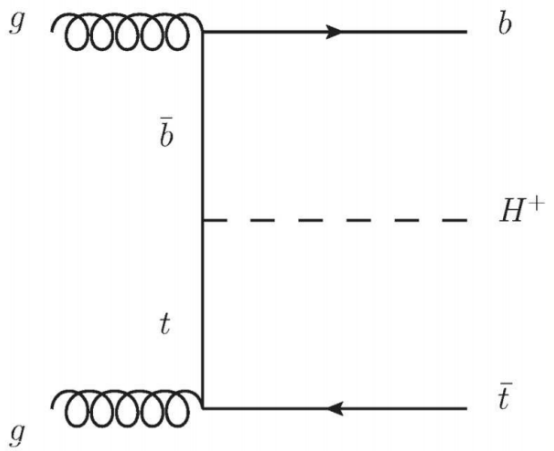




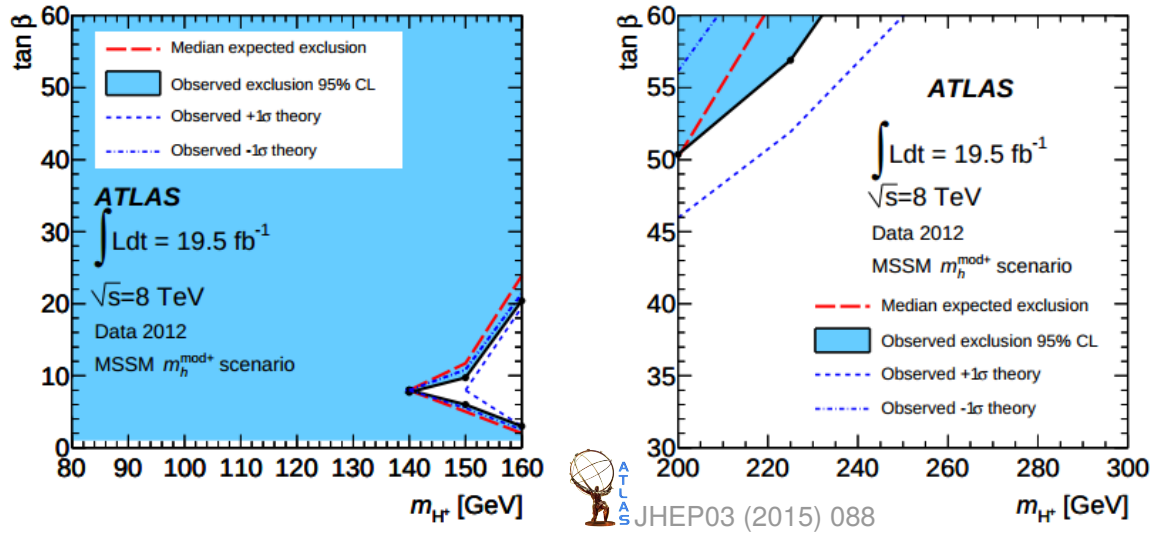
Sensitive up to tan $\beta \approx$5-7, complementary to $A \to \tau\tau$

PLB 744 (2015) 163-183

$H^{\pm}$ SEARCHES



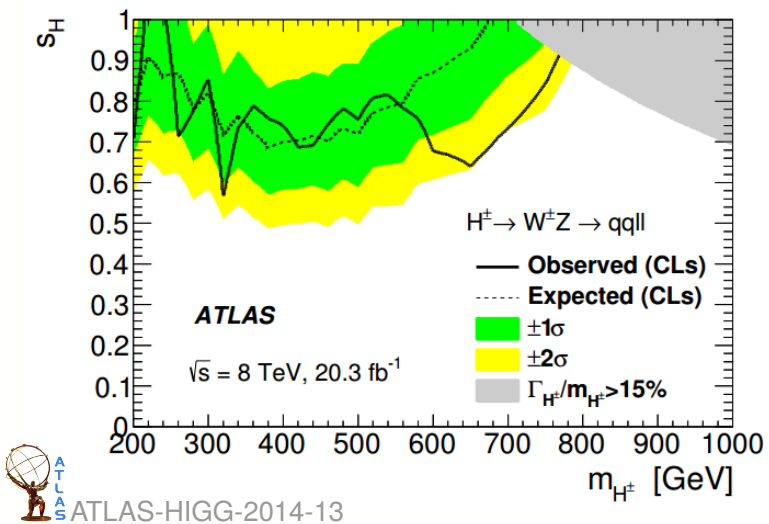
- *tb* decays dominating BR for high mass, but $\tau\nu$ decays have cleaner signature



JHEP03 (2015) 088

ATLAS $H^+ \to \tau\nu + jets$: most of the $m_{H\pm} \lesssim m_{top}$ region excluded

- Recently published search for VBF $H^{\pm} \to W^{\pm}Z$
- $H^{\pm} \to W^{\pm}Z$ appears at loop level in 2HDMs, but at tree level in Higgs Triplet Model
- Limits are set for 2HDM and for the Georgi-Machacek HTM
- Plot on the right is the limit for s_H, fraction of m_W^2 and m_Z^2 due to the triplet, in GMHTM

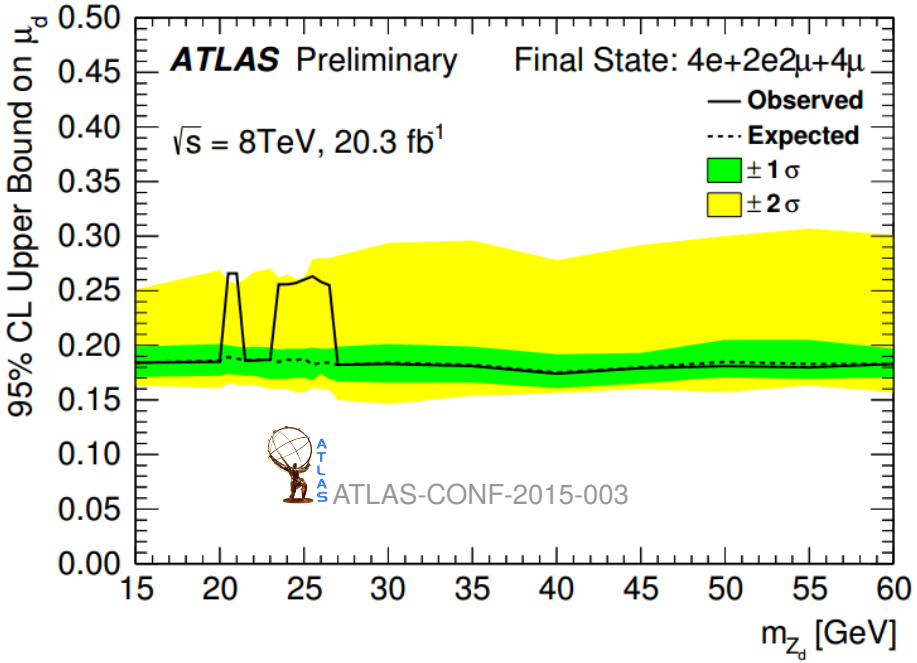


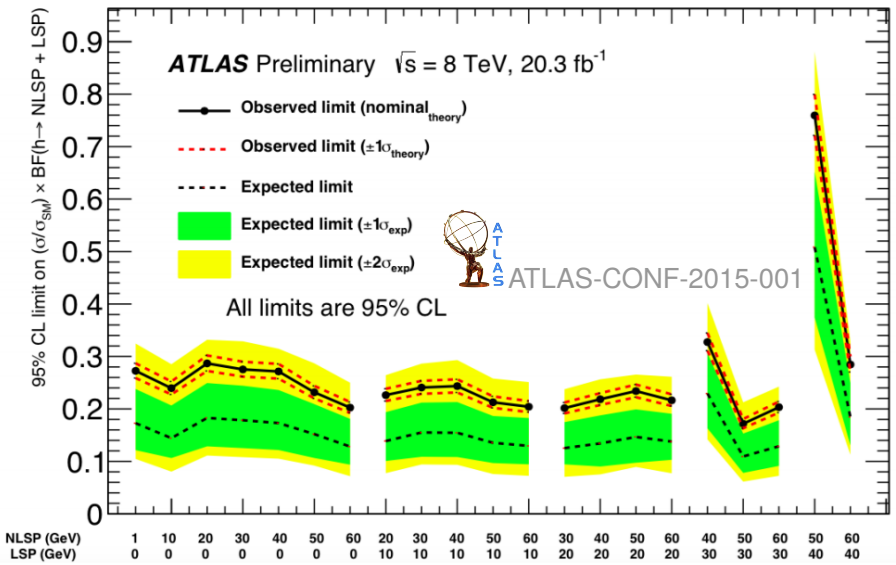
ATLAS-HIGG-2014-13

New results for "exotic" Higgs decays searches

$h \to ZZ_d \to 4\ell$ and $h \to Z_dZ_d\ 4\ell$

- Models with dark gauge symmetry mediated by vector boson Z_d
- ZZ_d : same selection as $h \to 4\ell$, search excess in $m_{\ell\ell}$
- Z_dZ_d: search in m_{Zd} for both pairs, 2 candidates found (both have local sign. $< 2\sigma$)





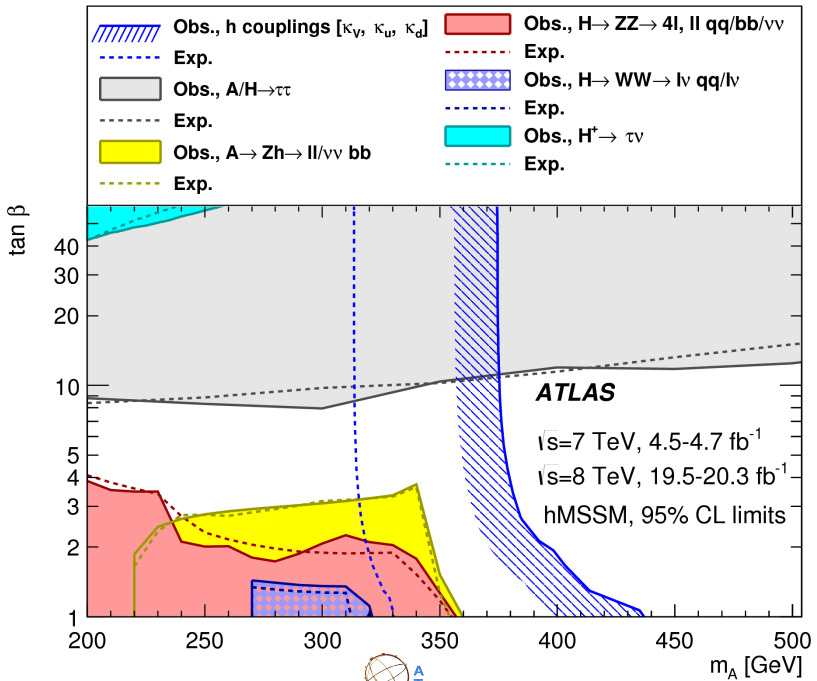
SUSY: h decays with $\geq 1\ \gamma$, E_T^{miss} and 2 forward jets

- Gauge mediated symmetry breaking (GMSB) models predict h decays to $\tilde{G}$ and $\tilde{\chi}_0$, with $\tilde{\chi}_0 \to \gamma + \tilde{G}$
- VBF production used to enhance sensitivity
- More stringent limits obtained for di-γ final states

Conclusions

- In Run I ATLAS carried out BSM Higgs searches to explore all possible extensions in the Higgs sector, only most recent presented here, some still in finalization
- No BSM physics discovery, but Run II just started:
  - looking forward for upcoming data!
- 8 TeV $\rightarrow$ 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}
  - $H/A \rightarrow \tau\tau$
  - $H \rightarrow \gamma\gamma$
  - $H \rightarrow ZZ \rightarrow 4\ell$
  - $H^+ \rightarrow \tau\nu$ + *jets*
  - double *h* production

Thanks!



arXiv:1509.00672

BACKUP

Ongoing analyses

- Constraints from SM Higgs couplings
- $H \to \gamma\gamma$
- $H \to WW \to e\nu\mu\nu$
- $H \to ZZ \to 4\ell$
- $H \to WW \to e\nu\mu\nu$ 2HDM
- $ZH \to \ell\ell$ + invisibles
- $h/H/A \to \tau^+\tau^-$
- $H \to hh \to b\bar{b}\gamma\gamma$
- $H \to hh \to b\bar{b}b\bar{b}$
- $H^\pm \to c\bar{s}$
- $H^\pm \to \tau^\pm\nu$
- $H^0 \to H^\pm(+X) \to h(+X)$
- $H^\pm$ search from lepton flavor violation
- $H \to WW$
- $H \to ZZ$
- Higgs invisible decays
- LFV: $H \to \mu\tau$
- Constrains from $H \to \gamma\gamma$
- $H \to aa \to \mu\mu\tau\tau$
- $A \to Zh$

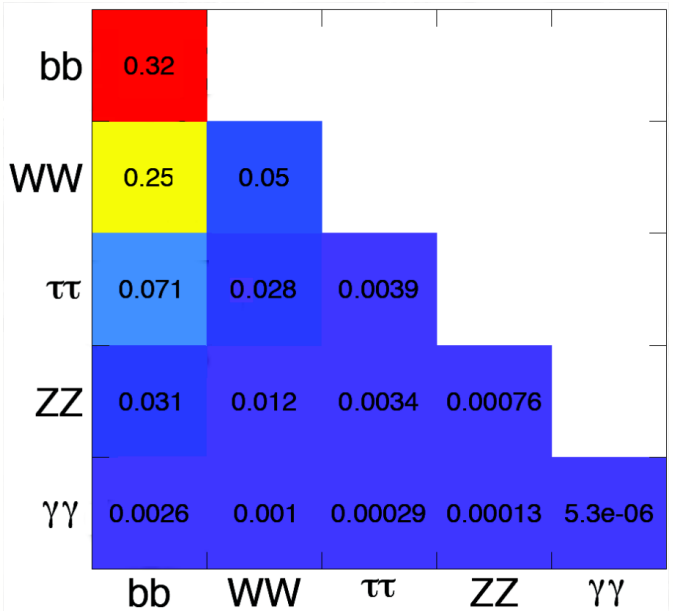
click on the analyses names for public webpage redirection

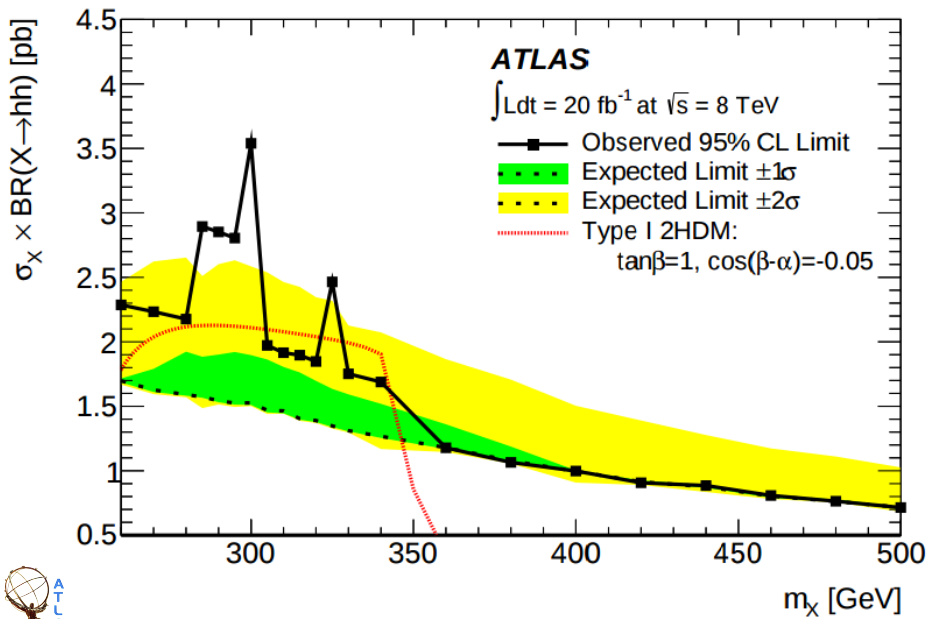
hh searches in Run-1

$H \to hh$ searches already sensitive to BSM models in Run-1, and important for preparation to long-term non-resonant *hh* measurements

- resonant: 2HDMs, hidden sectors, exotic models (e.g. gravitons), ...
- non-resonant enhancement: compositeness, colored scalars, 4th generation, ...

ATLAS publications: $hh \to bb\gamma\gamma$, $hh \to 4b$





PRL 114, 081802

$hh \to bb\gamma\gamma$

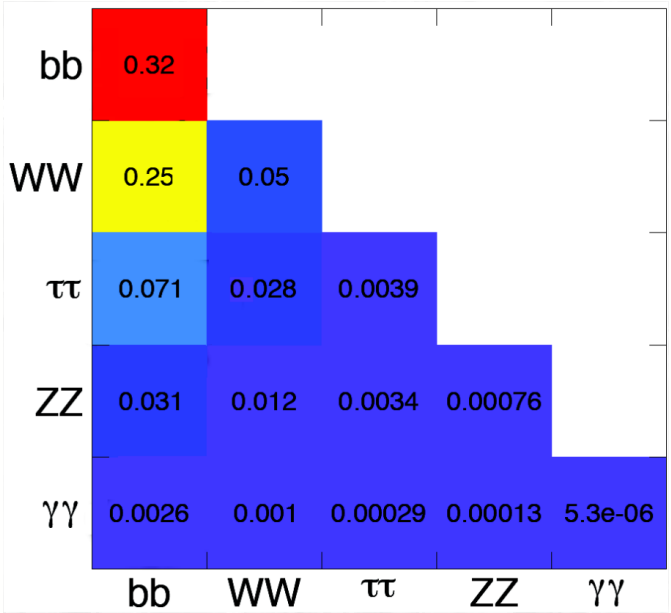
- Non-resonant: fit of continuum + SM *h* + BSM to $m_{\gamma\gamma}$
- Resonant: counting analysis cutting on $m_{\gamma\gamma}$ and $m_{bb\gamma\gamma}$
- Sensitive for $\tan\beta \approx 1$
- Observed (expected) for non-resonant production: 2.2 pb ($1.0^{+0.5}_{-0.2}$ pb)

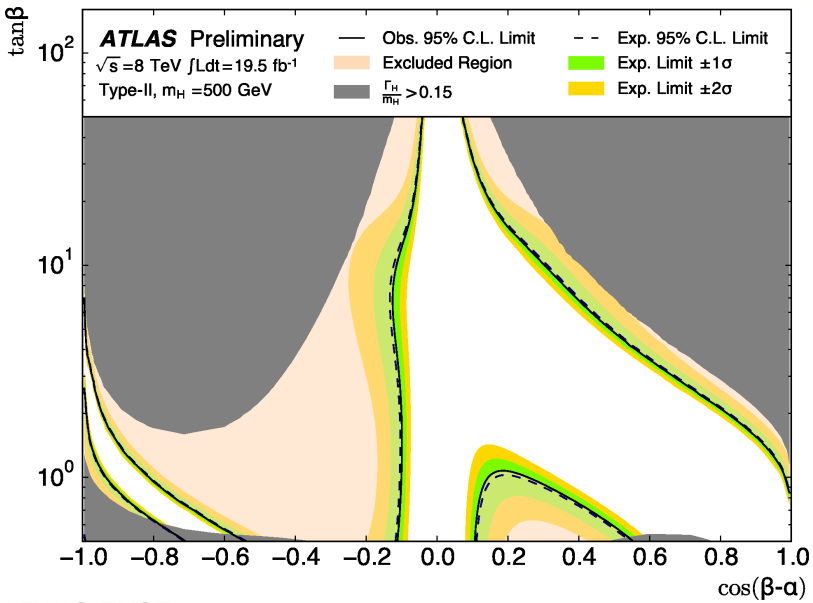
hh searches in Run-1

H → *hh* searches already sensitive to BSM models in Run-1, and important for preparation to long-term non-resonant *hh* measurements

- resonant: 2HDMs, hidden sectors, exotic models (e.g. gravitons), ...
- non-resonant enhancement: compositeness, colored scalars, 4th generation, ...

ATLAS publications: *hh* → *bbγγ*, *hh* → 4*b*





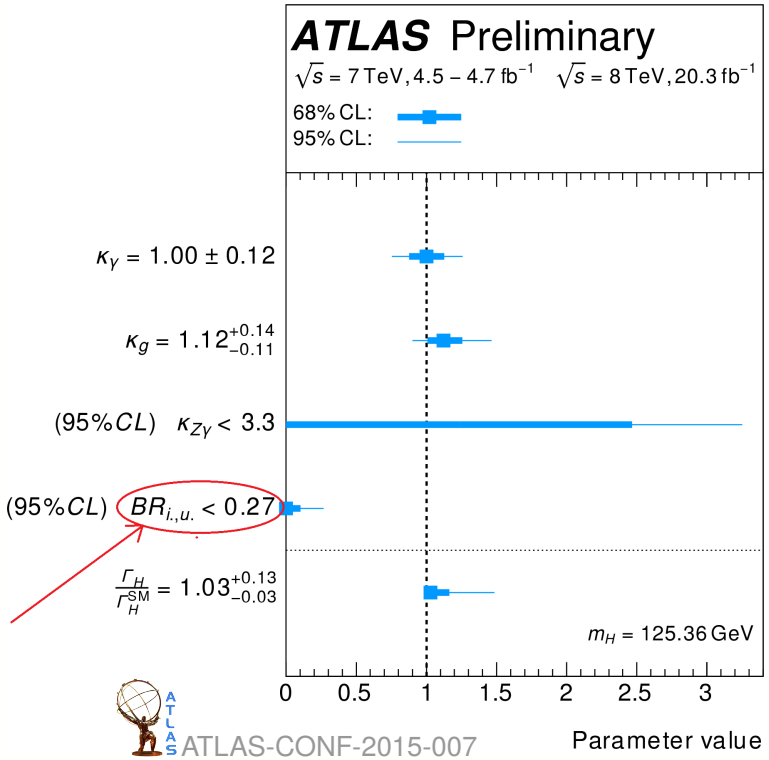
ATLAS-EXOT-2014-11

hh → 4*b*

- *hh* → 4*b* new paper soon in arXiv (preliminary results were in ATLAS-CONF-2014-005)
- Analysis performed both with resolved jets and for "fat"-jets, for boosted topologies (i.e. high mass)
- Limits set for resonances, e.g. KK graviton or additional Higgs in 2HDM, non-resonant limits set too

$h \rightarrow$ *invisible*

- Many BSM models predict invisible *h* decays
  - SUSY
  - extra-dimensions
  - 4th generation ν
  - ...
- Indirect measurement constraint
  BR($h \rightarrow$ *invisible*) to less than 30% (but with assumptions on other *h* couplings...)



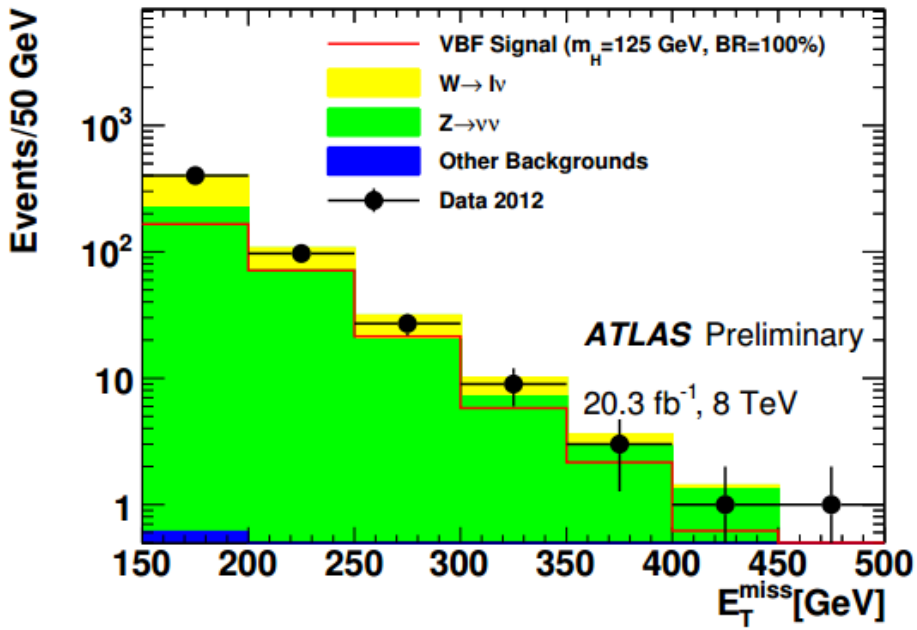
Direct measurements by ATLAS

- *Vh* with *V* $\rightarrow$ *hadrons*, *h* $\rightarrow$ *invisible* arXiv:1504.04324
- *VBF h* with *h* $\rightarrow$ *invisible* ATLAS-CONF-2015-004
- *Zh* with *Z* $\rightarrow \ell\ell$, *h* $\rightarrow$ *invisible* PRL 112, 201802 (2014)
- Mono-jet general search, with *h* $\rightarrow$ *invisible* results arXiv:1502.01518

VBF h WITH *h* → *invisible* ATLAS-CONF-2015-004

- 2 jets with $p_T^1 > 75$ GeV, $p_T^2 > 50$ GeV
- Veto for b/τ-tagging, veto for e/μ inside jets, veto for third jet
- $E_T^{miss} > 150$ GeV, $\Delta\eta_{jj} < 2.5$, $\Delta\eta_{j\not{E}_T} > 1$ to suppress QCD multi-jet
- Jets with big rapidity gap $\Delta\eta_{jj} > 4.8$, and $m_{jj} > 1$ TeV

- $Z \to \ell\ell$ and $W \to \ell\nu$ measured in data control samples
- Extrapolated to signal sample with correction factors evaluated with simulations
- Combined fit to event yields in signal and control samples



ATLAS-CONF-2015-004

- Observed (expcted) BR limit **29% (35%)** → comparable with indirect limit
- New result for *VH* with *V* → *hadrons*: **78% (86%)** arXiv:1504.04324
- Result from *Zh* with $Z \to \ell\ell$, *h* → *invisible*: **75% (63%)** PRL 112, 201802 (2014)