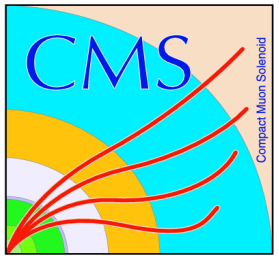




# Heavy neutral and charged Higgs boson searches in the MSSM and the 2HDM at ATLAS and CMS

Gerrit Van Onsem (DESY)
on behalf of the CMS and ATLAS collaborations

QCD@LHC 2016
Zürich, Switzerland
25 August 2016

HELMHOLTZ ASSOCIATION

DESY

# Observed Higgs boson may be part of extended sector

- Highlight of LHC Run 1: SM-like Higgs boson observed at m = 125 GeV by ATLAS and CMS

  **Maybe part of larger Higgs sector?**

- Many models beyond the SM predict **new (pseudo)scalar bosons**
  - Two-Higgs-Doublet models (2HDM)
  - Supersymmetry (MSSM)
  - Models with new electroweak Higgs singlets
  - Models with Higgs triplets
- 2HDM (and MSSM) predict two SU(2) doublets resulting in 5 physical Higgs bosons
  - **Charged $H^+$ and $H^-$**
  - **Neutral CP-even H and h**
  - **Neutral CP-odd A**

h often assumed to be observed Higgs boson at 125 GeV
→ leads to stringent constraints on allowed model parameter space

# Explored parameter space depends on model assumptions

> 2HDM benchmark models

- ***type-I*** one doublet couples to both up-type and down-type fermions
- ***type-II*** one doublet couples to up-type, other to down-type fermions

14 free parameters but can be reduced by assumptions

- tan(ß) ratio of the VEV of the two SU(2) doublets
- α mixing angle of mixing matrix
- $m_h$, $m_H$, $m_A$, $m_{H^\pm}$ physical masses of Higgs bosons
- $m_{12}$ $Z_2$ breaking mass parameter

> MSSM is example of 2HDM of *type-II*

- Usually scanning 2D plane of tan(ß) vs mass parameter

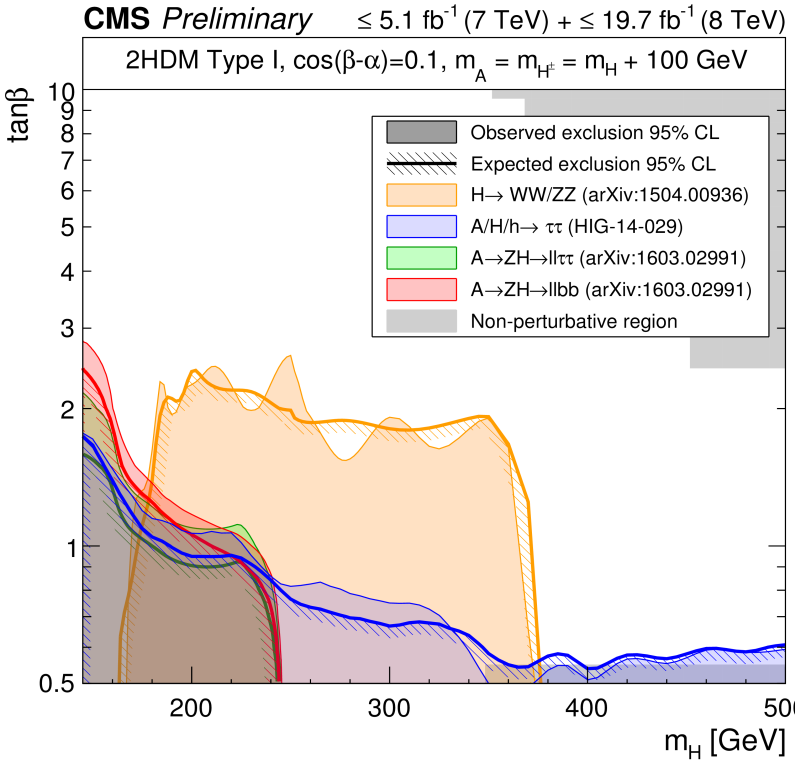
> New bosons could couple to fermions (τ, μ, t, b), SM bosons (h, W, Z) and each other

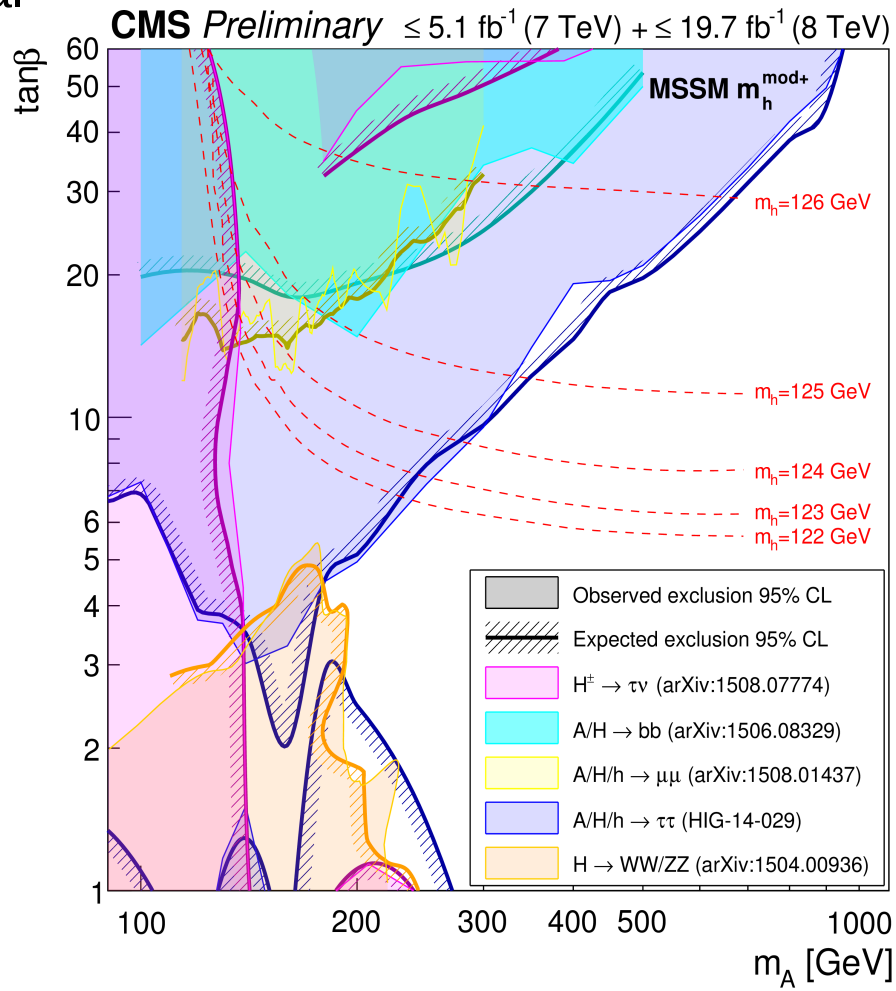
→ **rich phenomenology** at the LHC!

# BSM Higgs summary of CMS Run-1

HIG-16-007
CMS, 7+8 TeV

- **(Re)interpretation** of 8 CMS Run-1 analyses in 2HDM and MSSM models
- Choice of fixed parameters motivated from theory + experimental constraints
- Complementarity of experimental BSM searches **explores large part of parameter space**



# No significant signal observed in Run 1

> Some moderate excesses at 7+8 TeV *(some details in backup)*

| Search | Topology | Excess | Local σ | Global σ | Citation |
|---|---|---|---|---|---|
| H→WW | lνJ | 700 GeV | 2.6 | 0.5 combination | CMS, 1504.00936 |
| reso→Z+bb | llbb | $(m_{bb}, m_{llbb})$ = (95,285) GeV | 2.6 | 1.6 | CMS, 1603.02991 |
| | | $(m_{bb}, m_{llbb})$ = (575,660) GeV | 2.85 | 1.9 | |
| A→Zh | llbb | 560 GeV | 2.6 | 1.1 | CMS, 1504.04710 |
| $H^{\pm}$→tb | ttb(b) | 200-500 GeV | up to 2.4 | | ATLAS, 1512.03704 |
| reso→hh | various | 300 GeV (γγbb) | 2.5 | | ATLAS, 1509.04670 |

> No evidence or observations, but interesting channels to follow up at 13 TeV!

Charged $H^{\pm}$

- $H^{\pm} \rightarrow \tau\nu, tb$
- $H^{\pm} \rightarrow W^{\pm}Z$

H/A → fermions

- H/A → ττ
- H/A → bb
- H/A → tt

H → ZA, H/A → Zh

H/A → SM boson pair

- H → hh
- H → ZZ, WW

**Disclaimers:**
personal selection of searches, many results not covered in this talk!

Main focus on newer results, with CMS and ATLAS balance

Will not put much emphasis on comparison of results between experiments (note: sometimes requires careful evaluation of signal model assumptions)

**Charged $H^{\pm}$**

**$H^{\pm} \rightarrow \tau\nu, tb$**

**$H^{\pm} \rightarrow W^{\pm}Z$**

H/A → fermions

H/A → ττ

H/A → bb

H/A → tt

H → ZA, H/A → Zh

H/A → SM boson pair

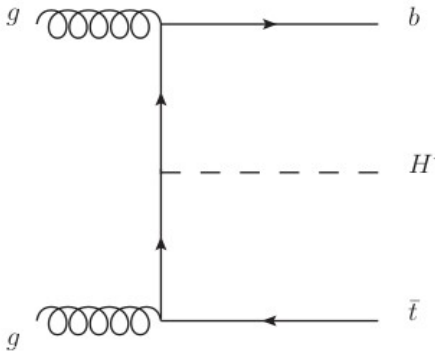
H → hh

H → ZZ, WW

# $H^{\pm} \rightarrow \tau\nu$

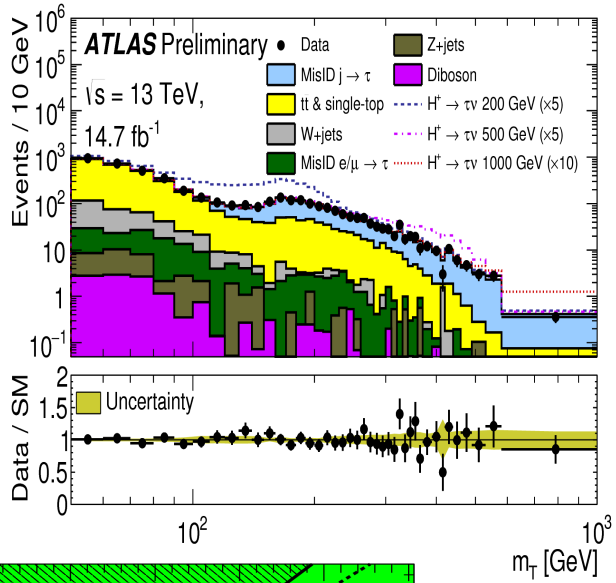
CONF-2016-088
ATLAS, 13 TeV

> Production of $H^{\pm} \rightarrow \tau\nu$ in association with top



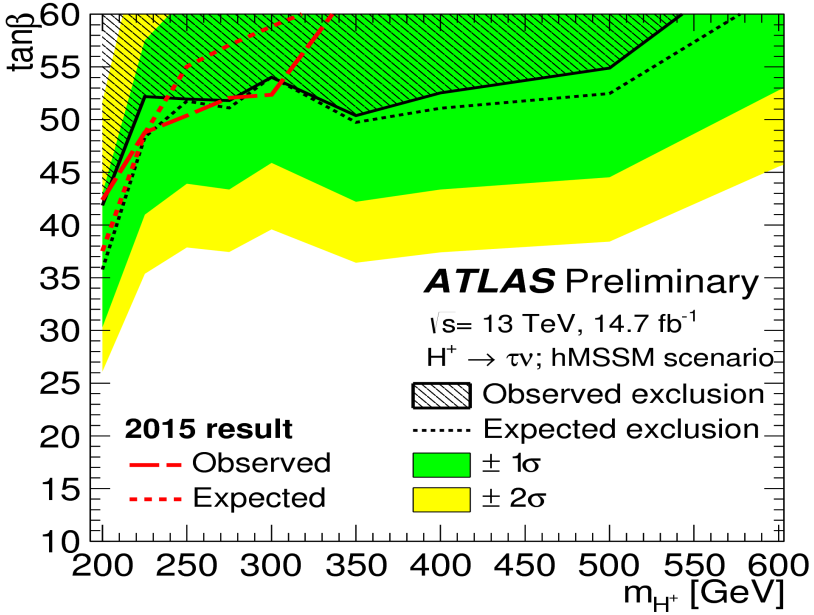

1 hadronically decaying $\tau_{\text{had-vis}}$
≥3 jets with ≥1 b-tag
MET > 150 GeV

$m_T$ of $\tau_{\text{had-vis}}$ and MET system




> Data-driven background estimation for jets identified as τ by applying fake factors from control regions

> Systematic uncertainties:
τ identification, tt modelling, energy scale of jets and τ, ...



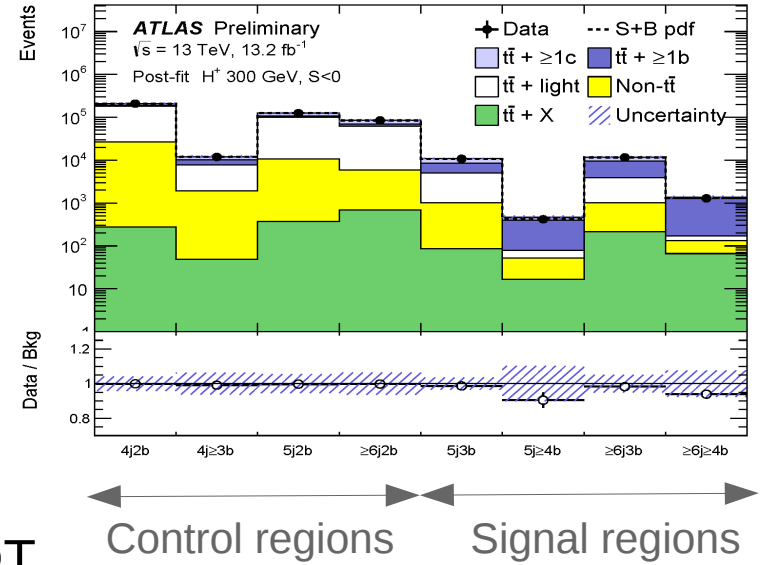
# $H^{\pm} \rightarrow tb$



- Production of $H^{\pm} \rightarrow tb$ in association with top

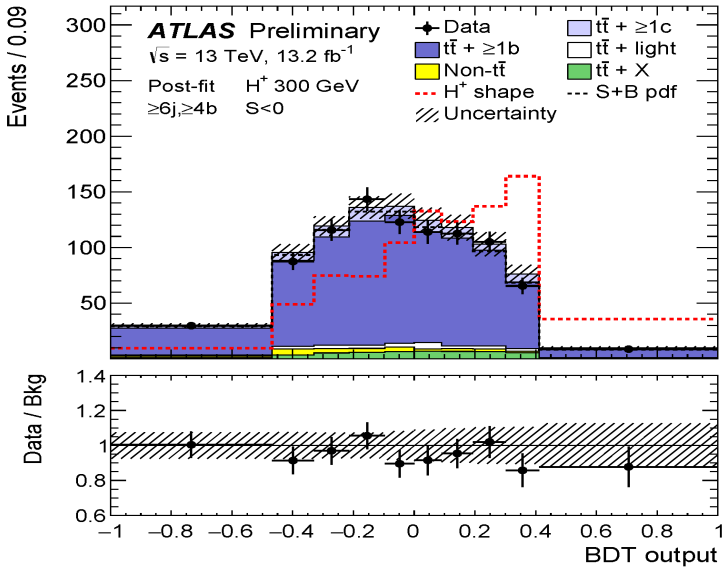
  1 lepton (electron or muon)
  ≥4 jets with ≥2 b-tag
  Veto events with $\tau_{had}$

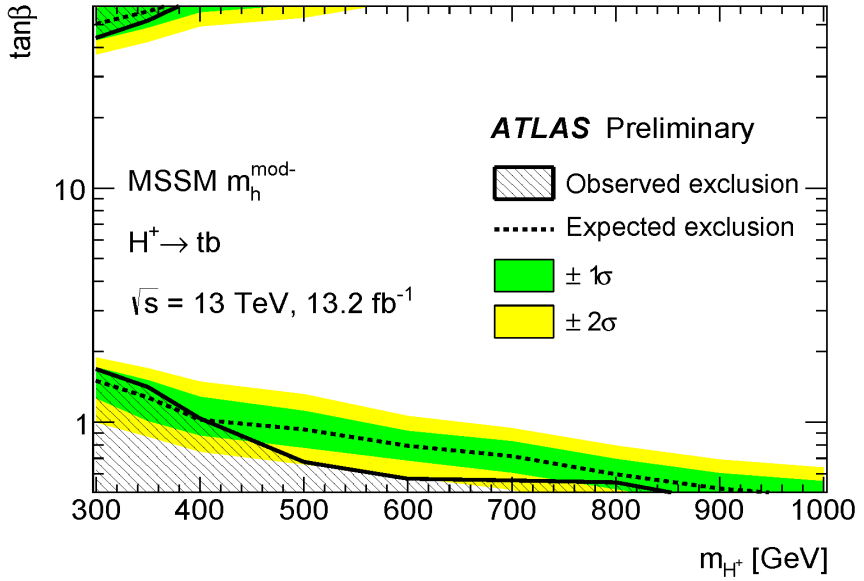
  4 control regions, 4 signal regions;
  based on number of jets and b-tagged jets




Control regions  Signal regions

- Discriminating variable in signal region: BDT
  using kinematic information of final state objects

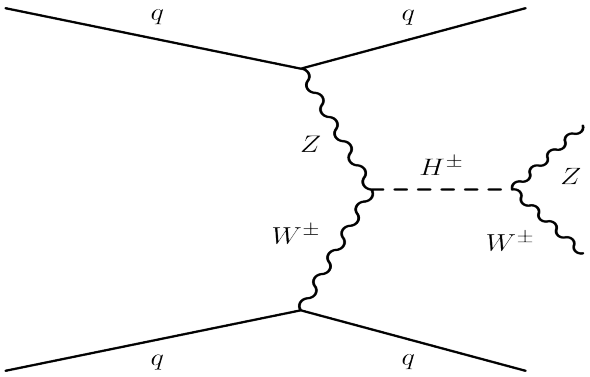


# $H^{\pm} \rightarrow W^{\pm}Z$

HIG-16-027
CMS, 13 TeV

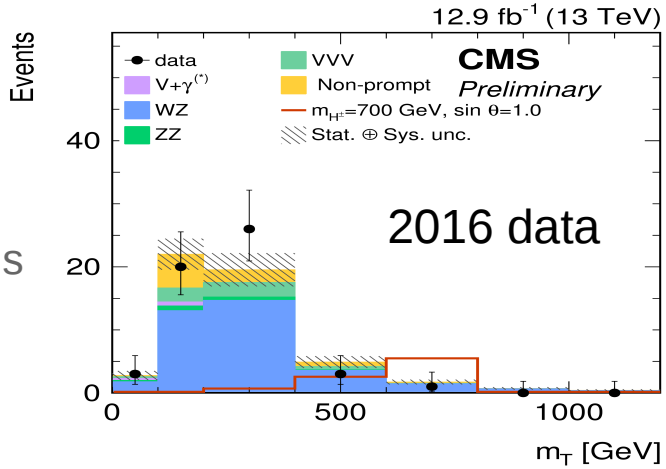
> Coupling in 2HDM only at higher order, in Higgs Triplet models at tree level




3 leptons (muon or electron)
MET > 30 GeV
2 jets, $|\Delta\eta_{jj}| > 2.5$
dijet mass > 500 GeV

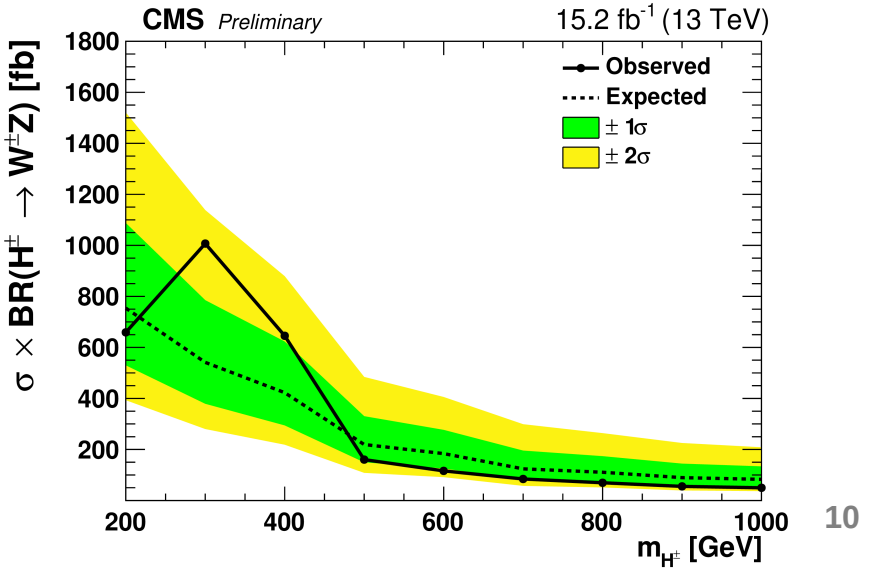
Z candidate from OSSF leptons

Discriminating variable:
transverse mass WZ system




> Dominating background WZ and non-prompt leptons (latter estimated from data using fake rate method)

> Systematics: WZ normalization (obtained from control region), non-prompt lepton background, jet energy scale, ...



Charged $H^{\pm}$

$H^{\pm} \rightarrow \tau\nu, tb$

$H^{\pm} \rightarrow W^{\pm}Z$

**H/A → fermions**

**H/A → ττ**

**H/A → bb**

**H/A → tt**

H → ZA, H/A → Zh

H/A → SM boson pair

H → hh

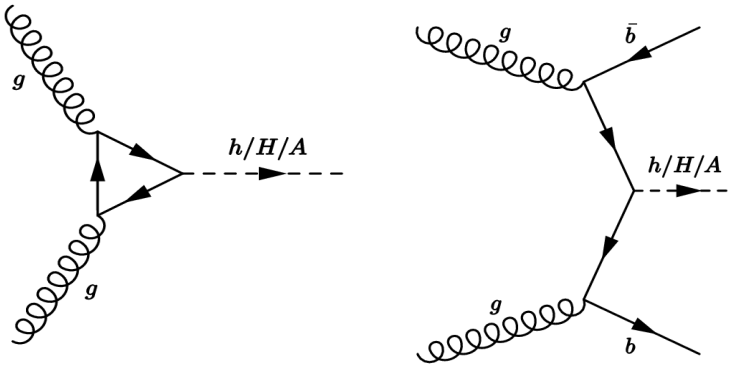
H → ZZ, WW

# H/A → ττ

CONF-2016-085 ATLAS, 13 TeV

HIG-16-006 CMS, 13 TeV

- Gluon fusion and b-associated production



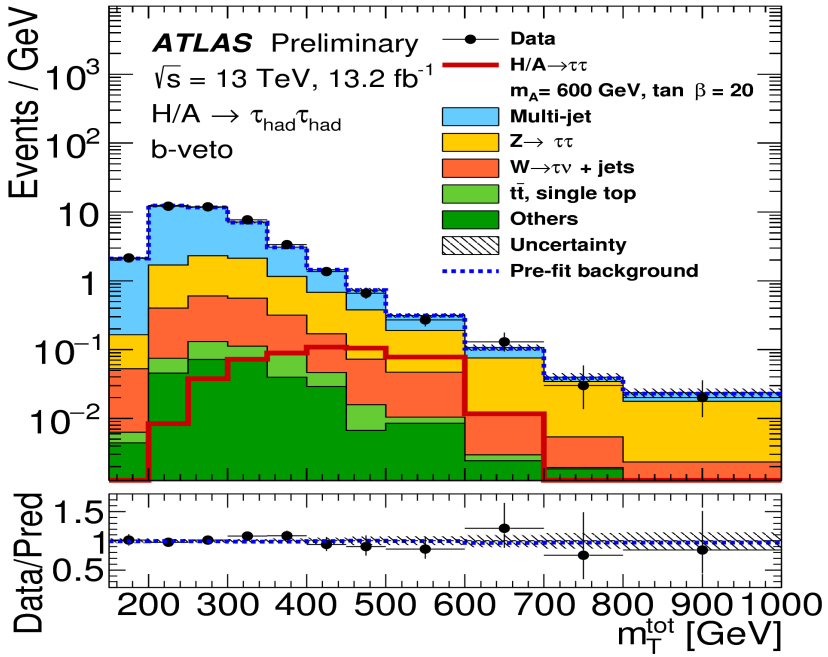

**$\tau_{lep}\tau_{had}$ channel**: 1 $\tau_{had\text{-}vis}$ and 1 lepton

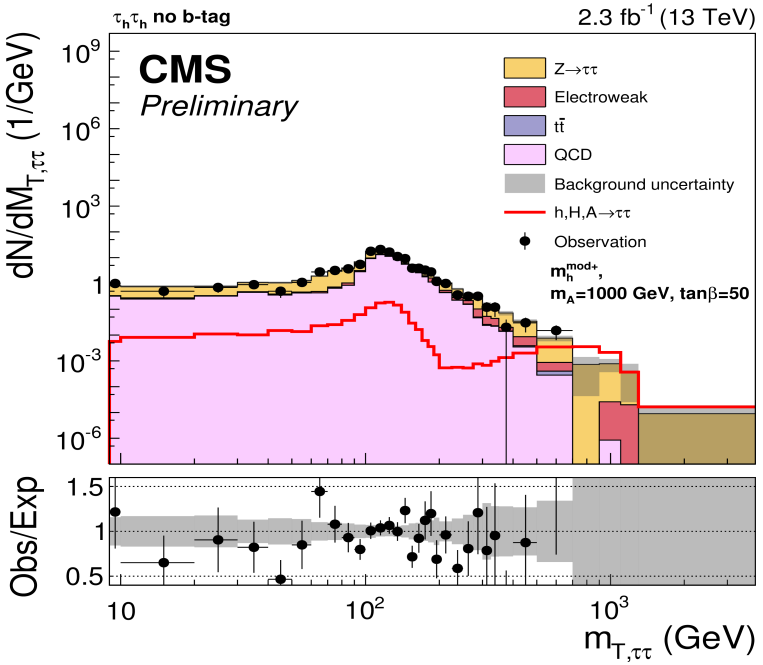
**$\tau_{had}\tau_{had}$ channel**: 2 $\tau_{had\text{-}vis}$

[CMS] **eμ channel**: 1 electron, 1 muon

Event categories according to presence of b-tagged jets

- Discriminating variable: **~transverse mass of di-tau system**



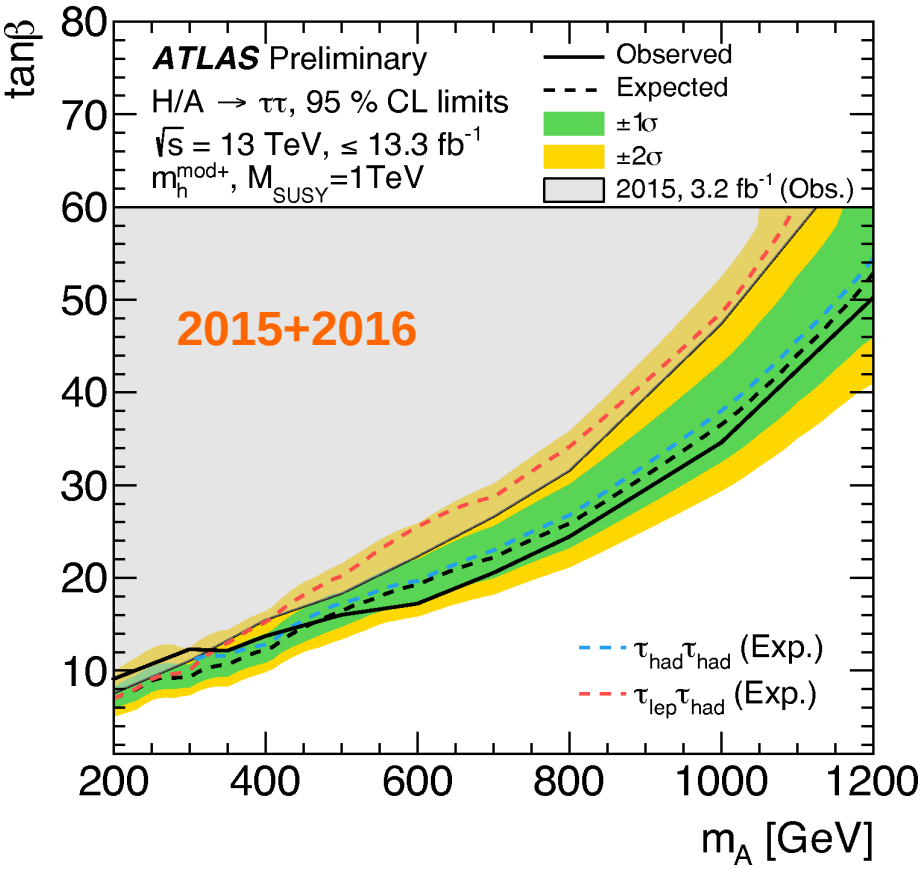



# H/A → ττ

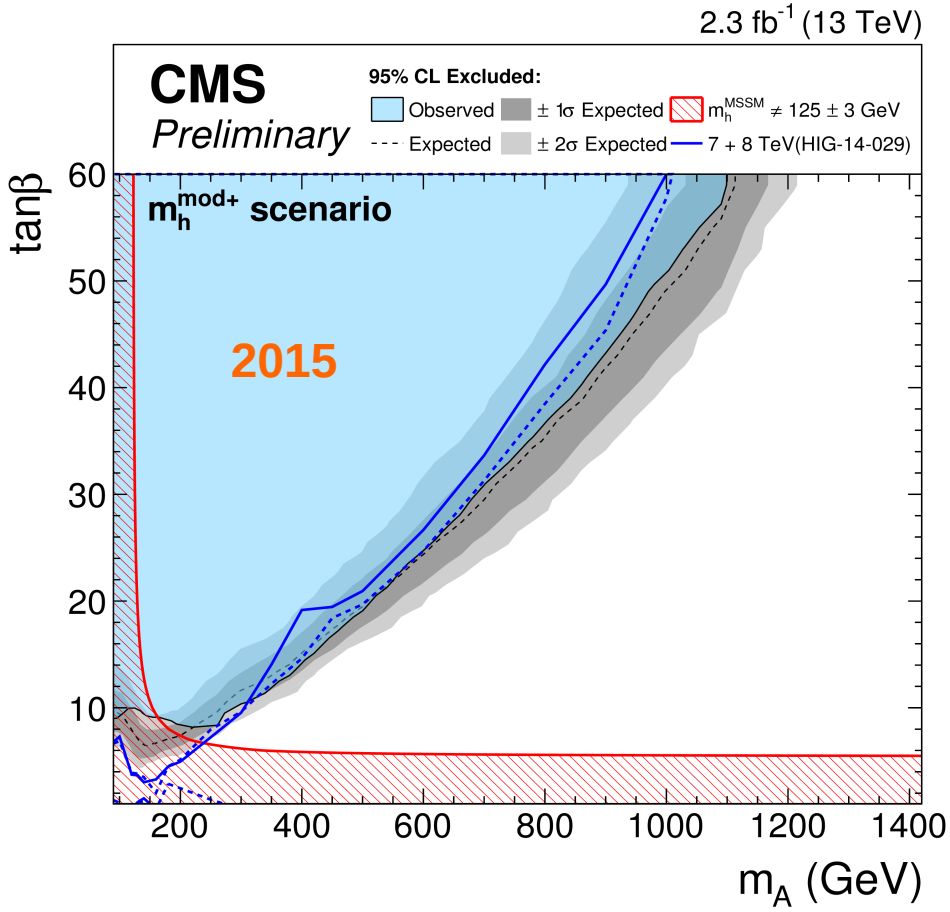
CONF-2016-085
ATLAS, 13 TeV

HIG-16-006
CMS, 13 TeV

> Systematic uncertainties ATLAS: top background parton shower modelling, $\tau_{had}$ energy scale, multijet estimation, ...




> Systematic uncertainties CMS: top background normalizations, $\tau_{had}$ mis-identification rate, τ trigger, ...



# H/A → bb

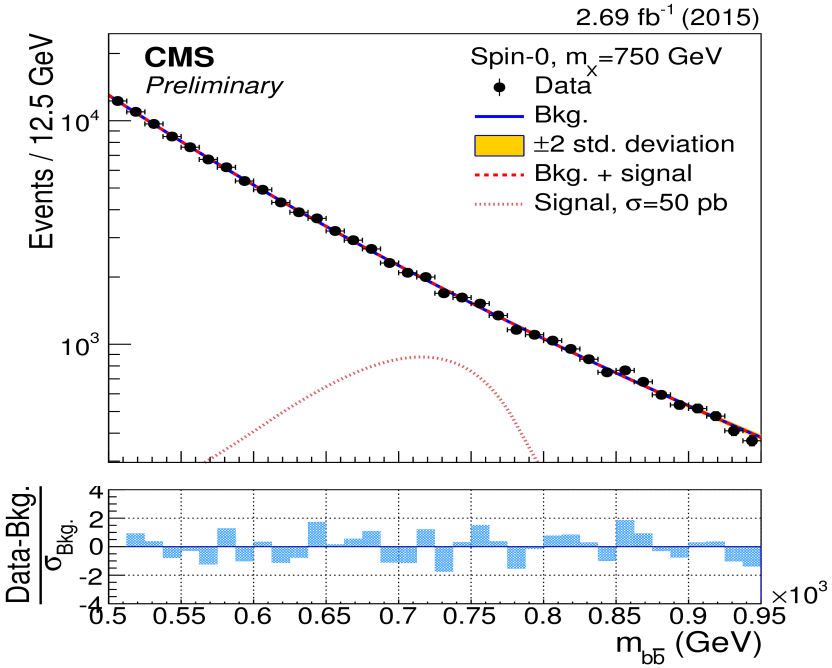


- Narrow spin-0 resonance, can be interpreted as a heavy Higgs boson

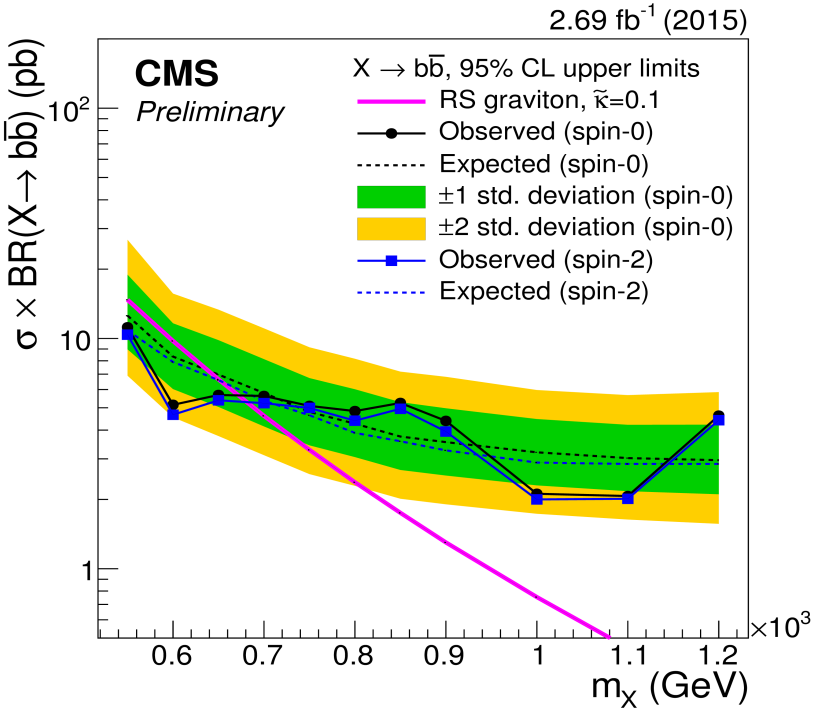
  ≥2 medium b-tagged jets with ≥1 also tight b-tagged
  2 jets with highest b-tag output: $p_T$ > 100 GeV and $\Delta\eta_{bb}$ < 1.6
  veto on leptons

- Background prediction of $m_{bb}$ variable from smooth data-derived function

Signal parametrized as convolution of gaussian with exponential



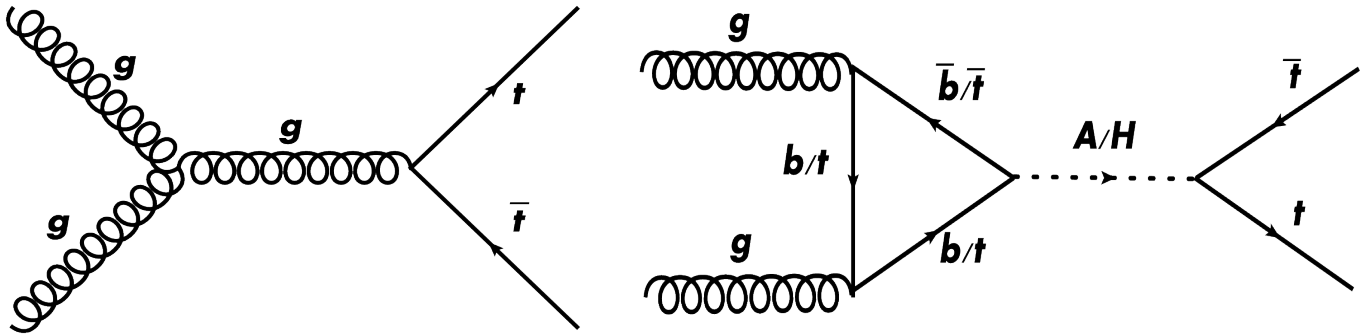

Systematics: jet energy resolution, b-tagging, choice of background PDF, ...



# H/A → tt

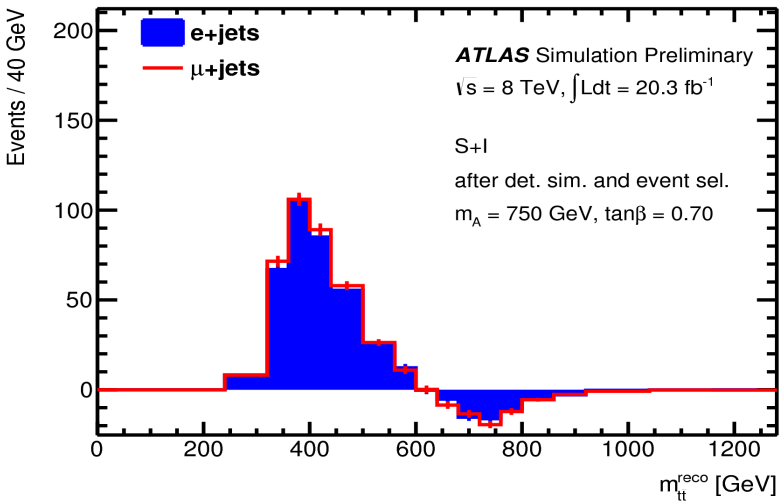
CONF-2016-073
ATLAS, 8 TeV

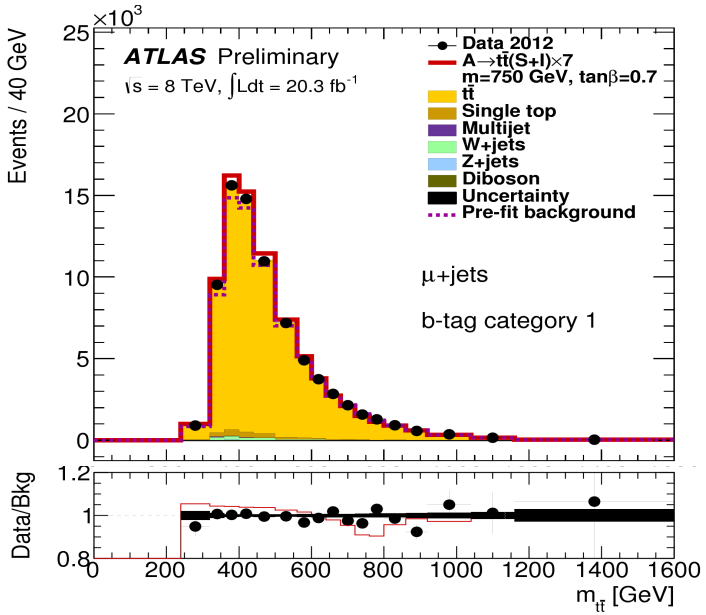
- If new Higgs boson mass above $2m_t$ threshold, decay to top pair allowed




1 muon or electron
≥ 4 jets
≥ 1 b-tagged jets
MET > 20 GeV

- Semileptonic top pair system reconstruction via kinematic fit
- Interference effects between SM tt and H/A → tt create 'peak-dip' structure in $m_{tt}$ distribution



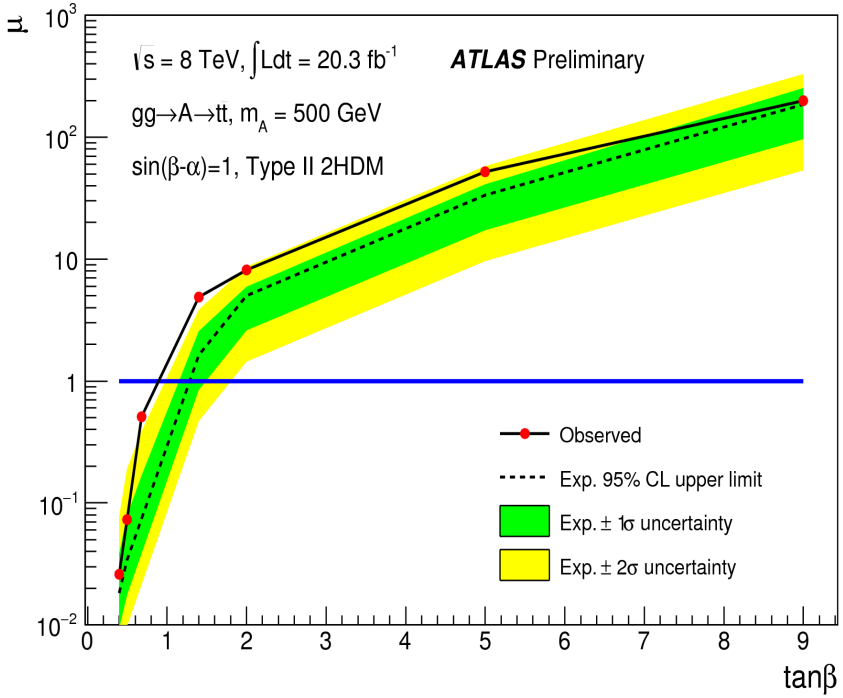



# H/A → tt

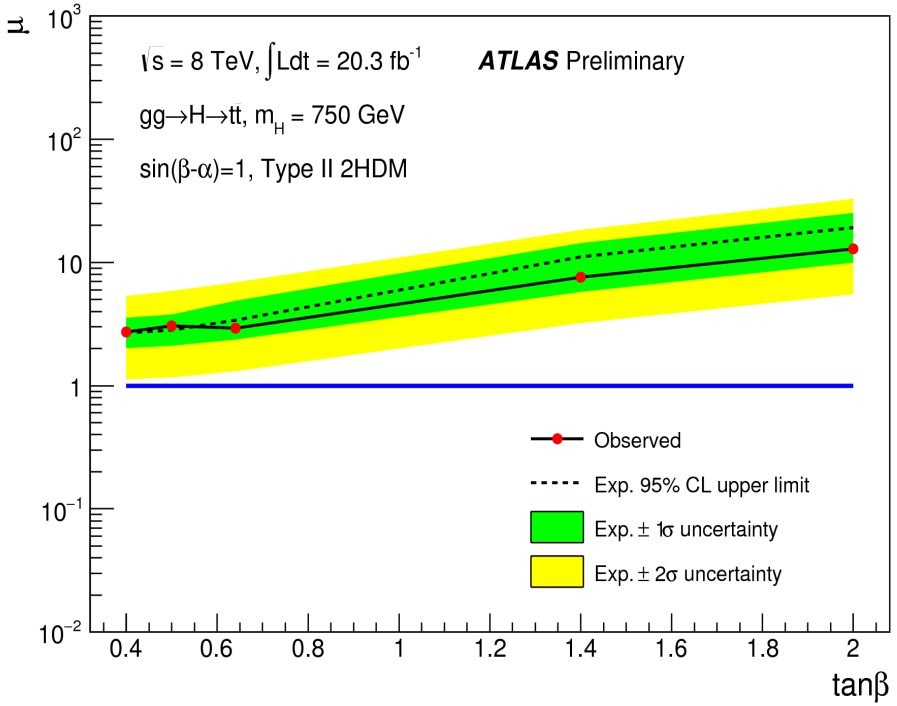
CONF-2016-073
ATLAS, 8 TeV

- Systematic uncertainties: jet energy scale and resolution, tt cross section, parton density functions, ...
- Upper limits on signal strength (non-trivial scaling of resonance and interference parts) vs tanβ

pseudoscalar mass 500 GeV




scalar mass 750 GeV



Charged $H^{\pm}$

- $H^{\pm} \rightarrow \tau\nu, tb$
- $H^{\pm} \rightarrow W^{\pm}Z$

H/A → fermions

- H/A → ττ
- H/A → bb
- H/A → tt

**H → ZA, H/A → Zh**

H/A → SM boson pair

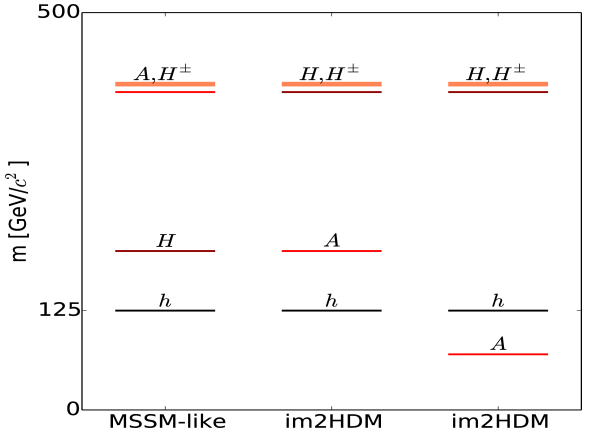
- H → hh
- H → ZZ, WW

# H → ZA

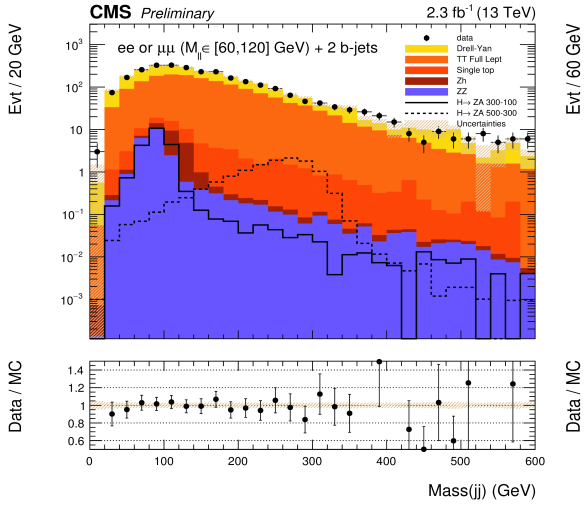
HIG-16-010
CMS, 13 TeV

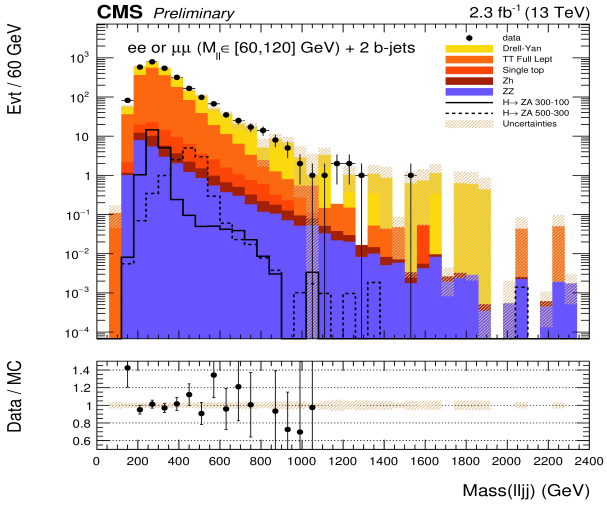
- Mass hierarchy might allow decay of one new Higgs boson to another
- Consider decay of H to Z (decaying to 2 leptons) and A (decaying to 2 b quarks)

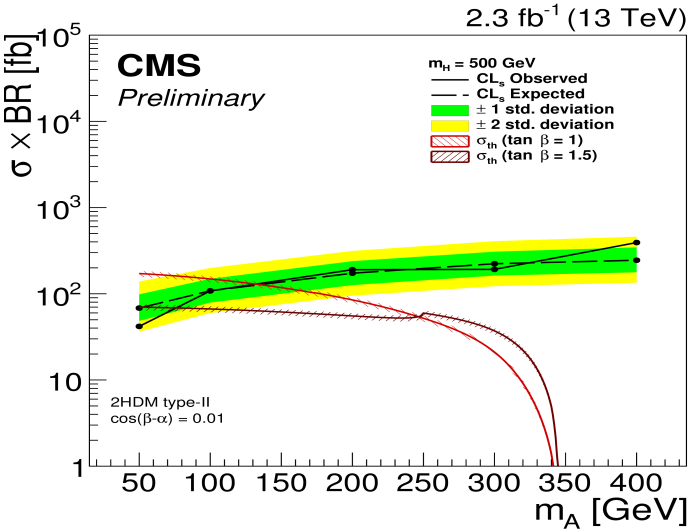
  2 OSSF leptons
  ≥2 b-tagged jets




- Depending on ($m_H$, $m_A$) hypothesis, consider rectangular signal region in ($m_{llbb}$, $m_{bb}$) plane and use inverse as control region



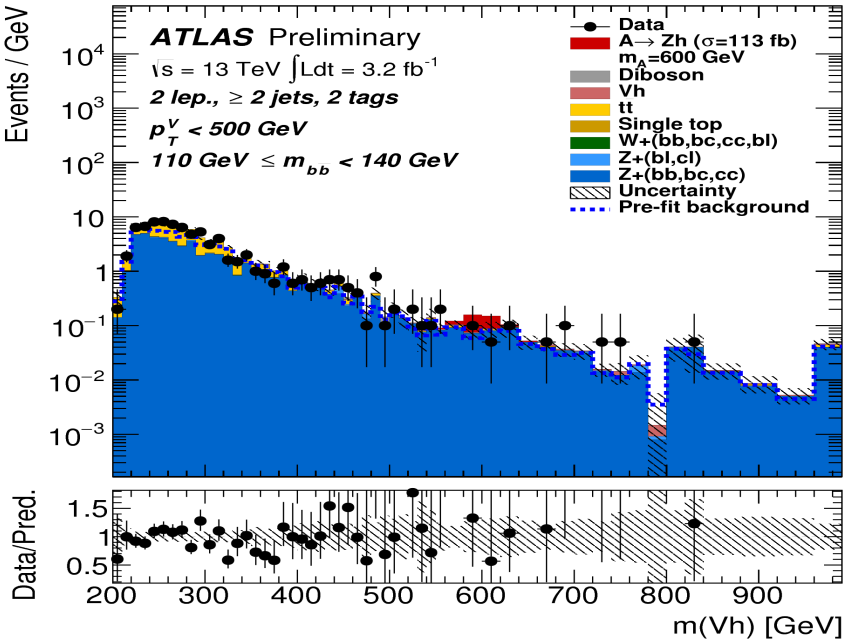
# A → Zh

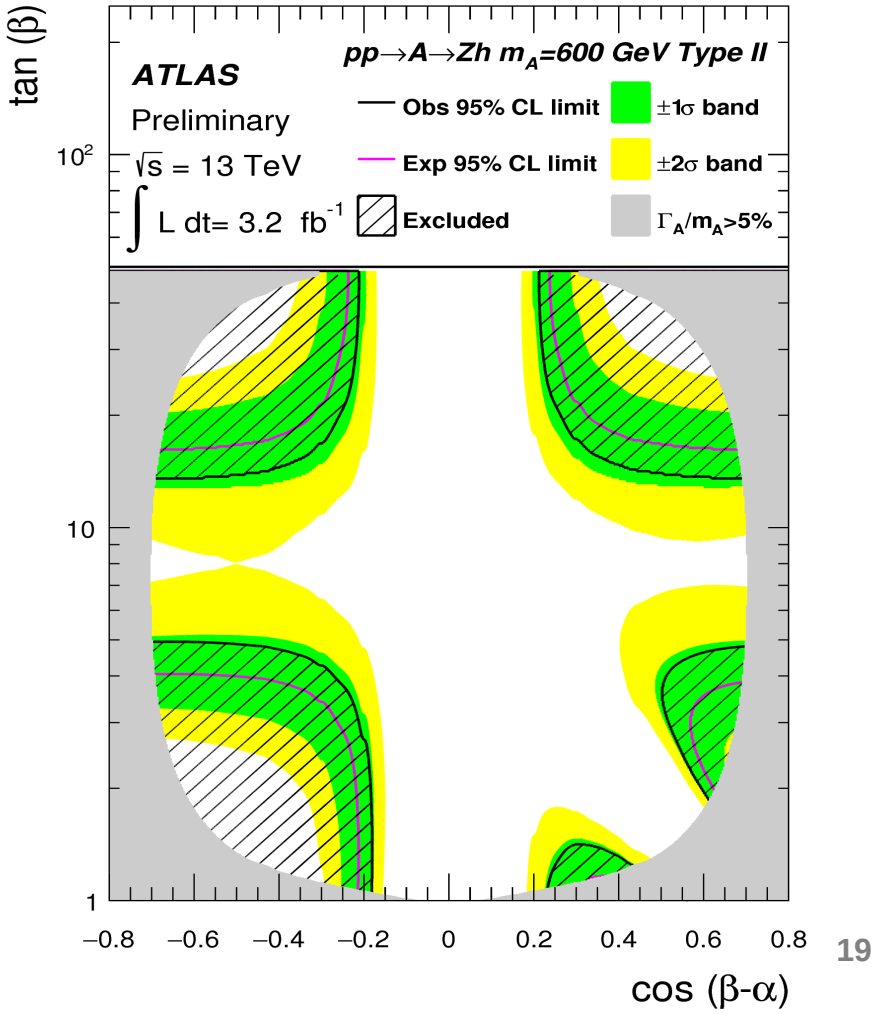


- Channels targeted: Z → ee, μμ, νν and h → bb

  **categories** based on #charged leptons (0 or 2), $p_T$ Z candidate, #b-tagged jets (1 or 2)

- Discriminating variables
  - Transverse mass (0-lepton)
  - mass llbb system (2-lepton)



Charged $H^{\pm}$

- $H^{\pm} \rightarrow \tau\nu, tb$
- $H^{\pm} \rightarrow W^{\pm}Z$

H/A → fermions

- H/A → ττ
- H/A → bb
- H/A → tt

H → ZA, H/A → Zh

**H/A → SM boson pair**

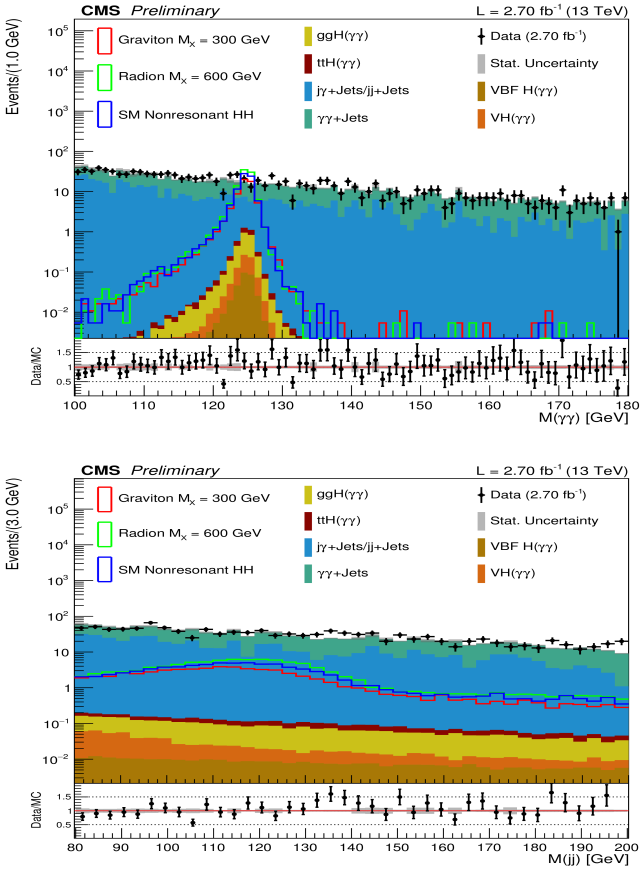
- **H → hh**
- **H → ZZ, WW**

# H → hh

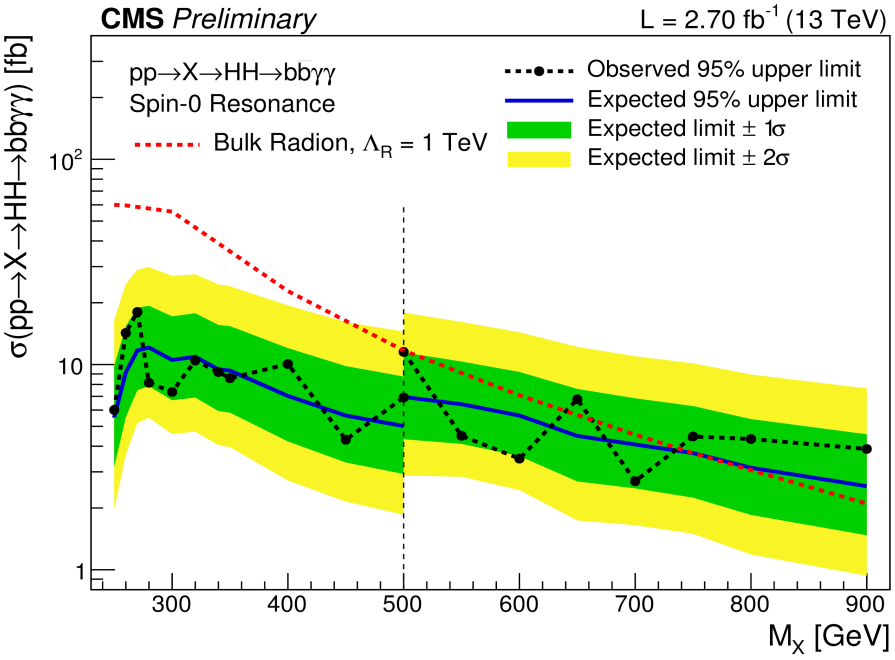
HIG-16-032
CMS, 13 TeV

> Search for resonant production of two SM-like h bosons (hh → bbγγ)

≥2 photon candidates
dijet candidate (2 jets with highest b-tag scores)
window of mass(jjγγ) depending on signal hypothesis




> Parametric fit of 2D plane defined by diphoton and dijet mass

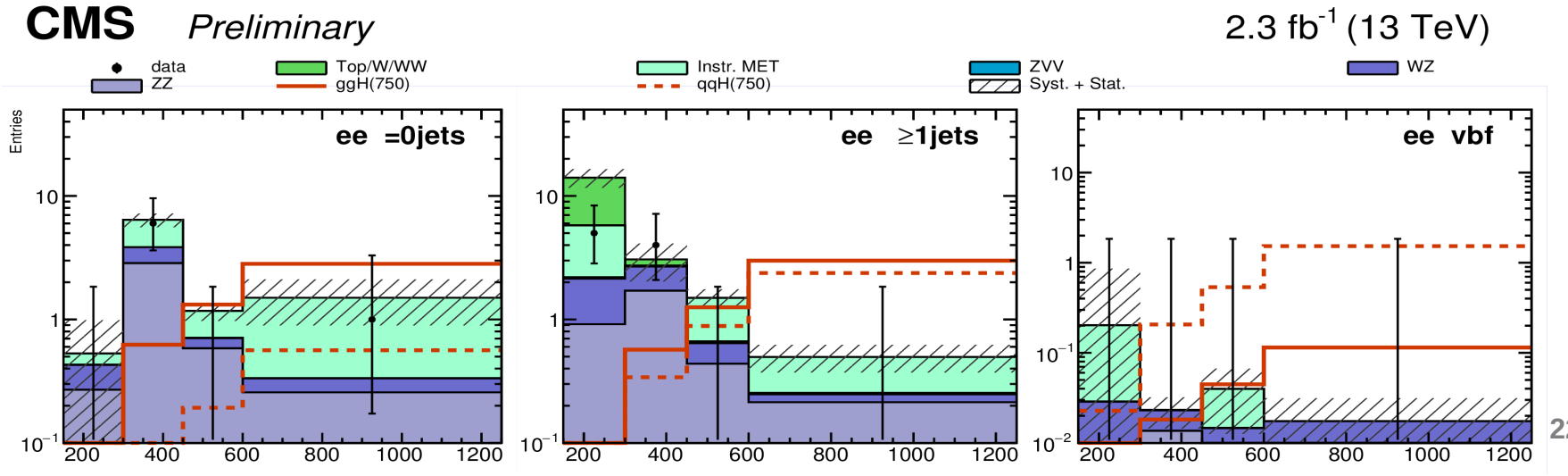



**Backup: example of H → hh → bbbb** (ATLAS, 1606.04782)
excluding cross section x BR above 300 fb in range [0.5,3.0] TeV

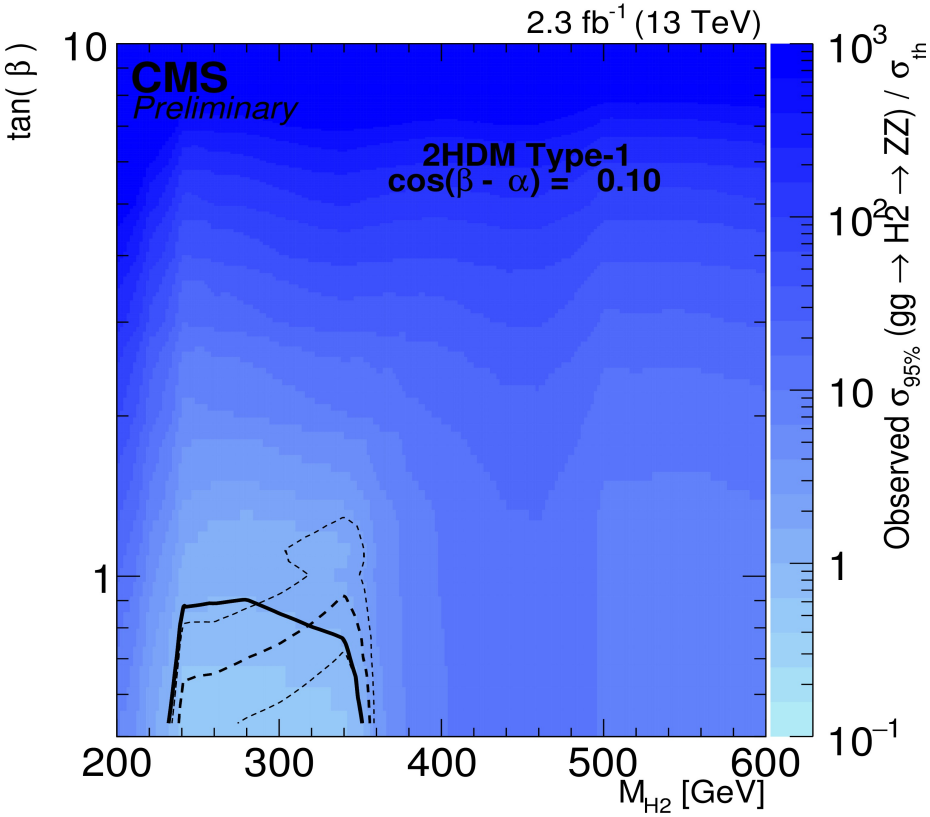
# H → ZZ

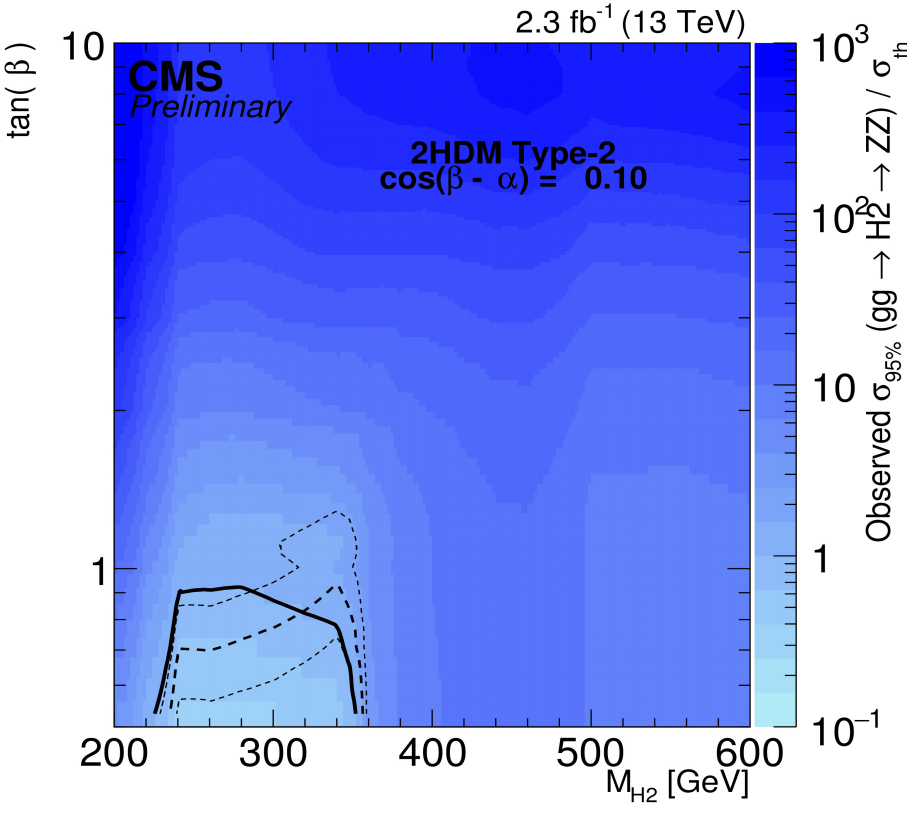
HIG-16-001
CMS, 13 TeV

- Search for heavy scalar boson decaying to ZZ → 2l2v
  - 2 OSSF leptons (muons or electrons)
  - $p_T$ dilepton > 55 GeV
  - MET ≥ 125 GeV
- Jet multiplicity categories
  - VBF category: ≥2 jets with large pseudorapidity gap and high mass
  - ≥1 jets failing VBF
  - 0 jets
- Discriminating variable: $m_T$ of dilepton and MET system



- Systematic uncertainties: QCD scale in simulation, jet energy scale, background estimation, ...
- Interpretation in type-I and type-II 2HDM models



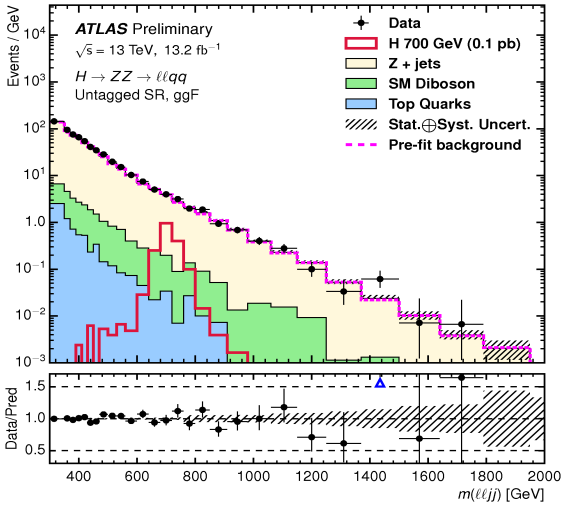
# H → ZZ

CONF-2016-082
ATLAS, 13 TeV

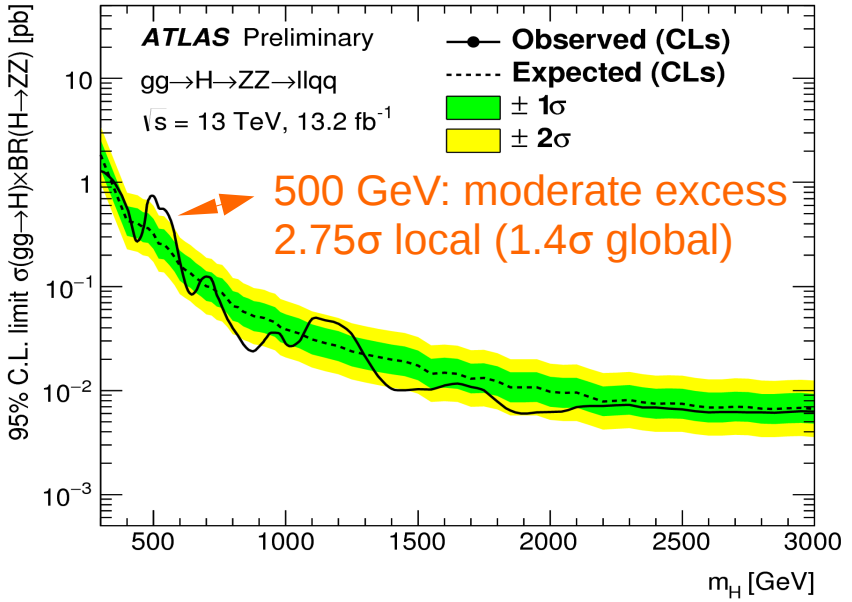
- 2-lepton analysis (llqq channel)
  - OSSF electrons or muons in Z mass window
  - large-R jet (decay products from Z merged) or ≥2 small-R jets (not merged)

  0-lepton analysis (ννqq channel)
  - MET > 250 GeV, veto on leptons
  - large-R jet

Mass (dilepton,dijet)




- Systematics: large-R jet energy scale and resolution, W/Z+jets modelling, …
- Interpretation as new heavy scalar



# Summary

- Observed Higgs boson at mass 125 GeV may be part of an **extended Higgs sector**
- Many BSM models predict **new scalar, pseudoscalar and charged or neutral Higgs bosons** (2HDM, MSSM, …)
- **Rich phenomenology**, extensive experimental program in ATLAS/CMS

  Many searches at 7 TeV, 8 TeV and now 13 TeV found **no evidence**

  13 TeV results more stringent in much of the parameter space (but not all)
- Currently only few small excesses at 13 TeV exceeding 2σ
  *(some details in backup)*

| Search | Topology | Excess | Local σ | Global σ | Citation |
|---|---|---|---|---|---|
| reso→ZZ/WZ | llqq | 500 GeV | 2.75 | 1.4 | ATLAS, CONF-2016-082 |

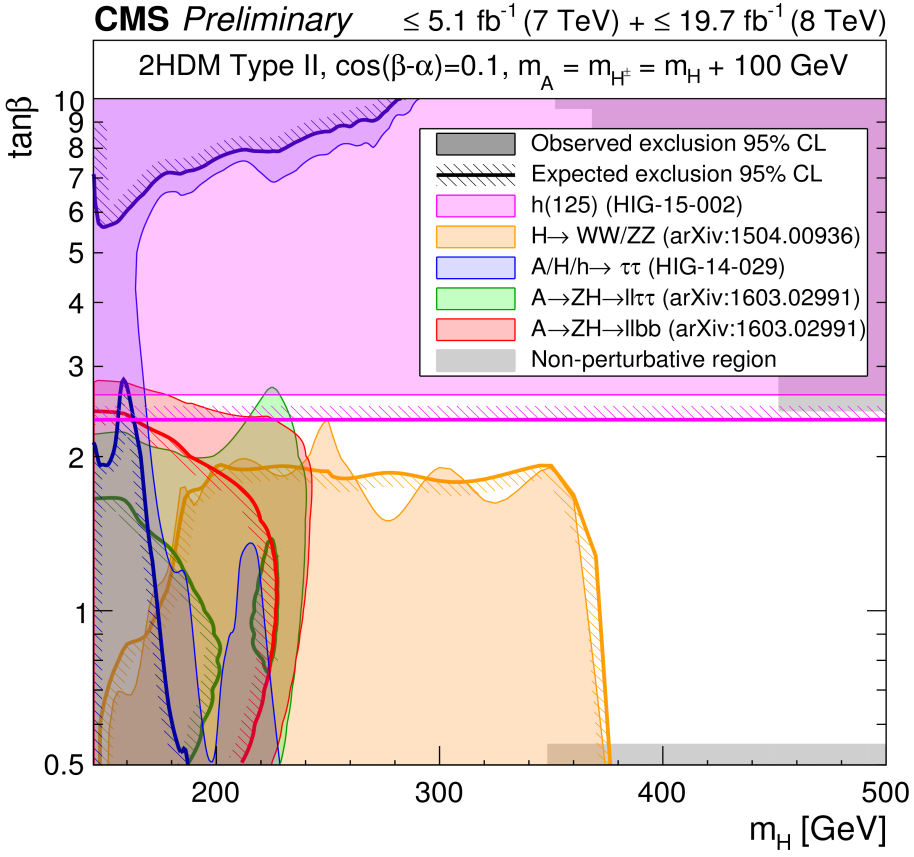
- **Many exciting results expected** in the near future!

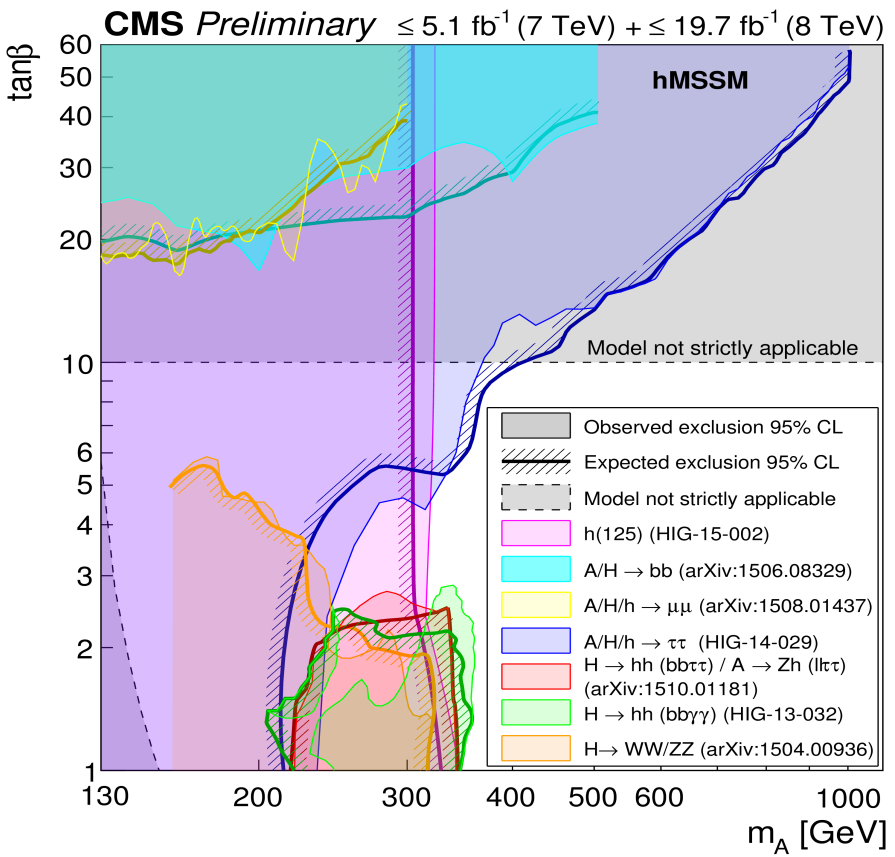

BACKUP

# BSM Higgs summary of CMS Run-1

HIG-16-007
CMS, 7+8 TeV

> Additional limit summary plots

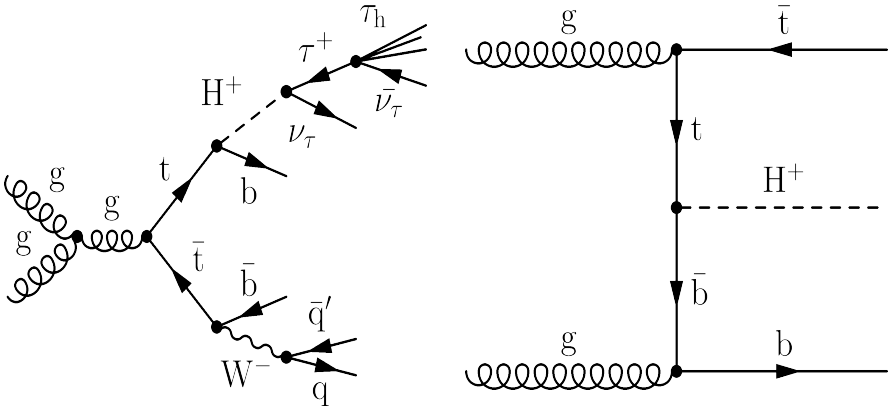


# $H^{\pm} \rightarrow \tau\nu$, tb

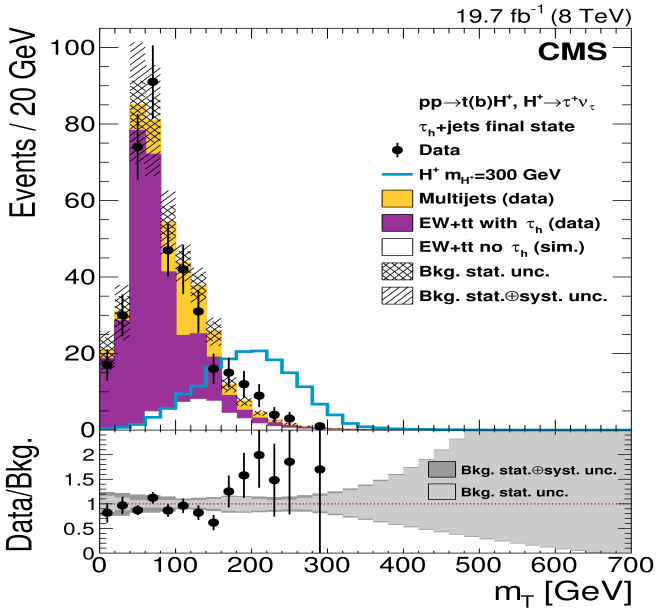
1508.07774
CMS, 8 TeV

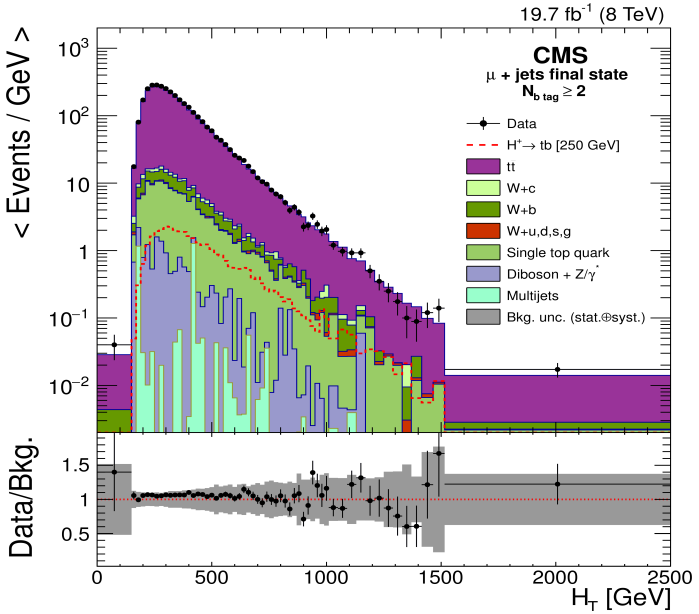
> Production/decay dependency on mass hierarchy of $H^{\pm}$ and top




| Decay mode | Signatures for $m_{H^+} < m_t - m_b$ | Signatures for $m_{H^+} > m_t - m_b$ |
|---|---|---|
| | $pp \rightarrow t\bar{t} \rightarrow bH^+\bar{b}H^-/bH^+\bar{b}W^-$ | $pp \rightarrow \bar{t}(b)H^+$ |
| $H^+ \rightarrow \tau^+\nu_\tau$ | $\tau_h$+jets$^{(5)}$ | $\tau_h$+jets$^{(5)}$, $\mu\tau_h^{(6)}$, $\ell\ell'^{(7)}$ |
| $H^+ \rightarrow t\bar{b}$ | — | $\mu\tau_h^{(6)}$, $\ell\ell'^{(7)}$, $\ell$+jets$^{(8)}$ |

> Discriminating variables: transverse mass $m_T$ of $\tau_{had}$ and MET system, b-tagged jet multiplicity, and $H_T$ (scalar sum of $p_T$ of jets)

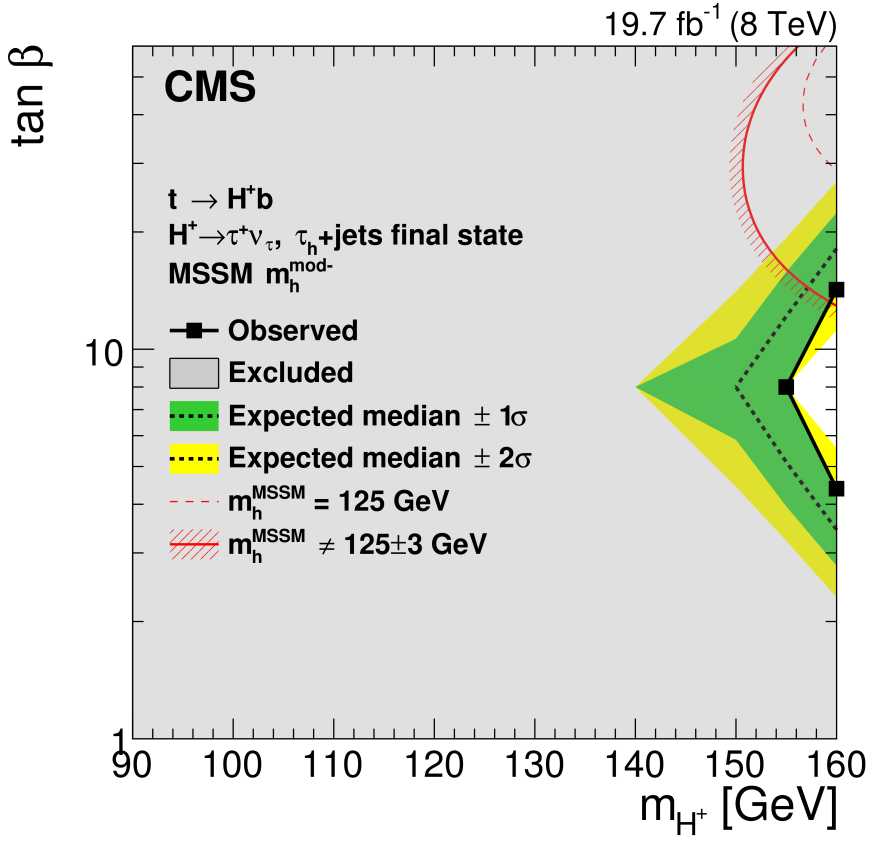


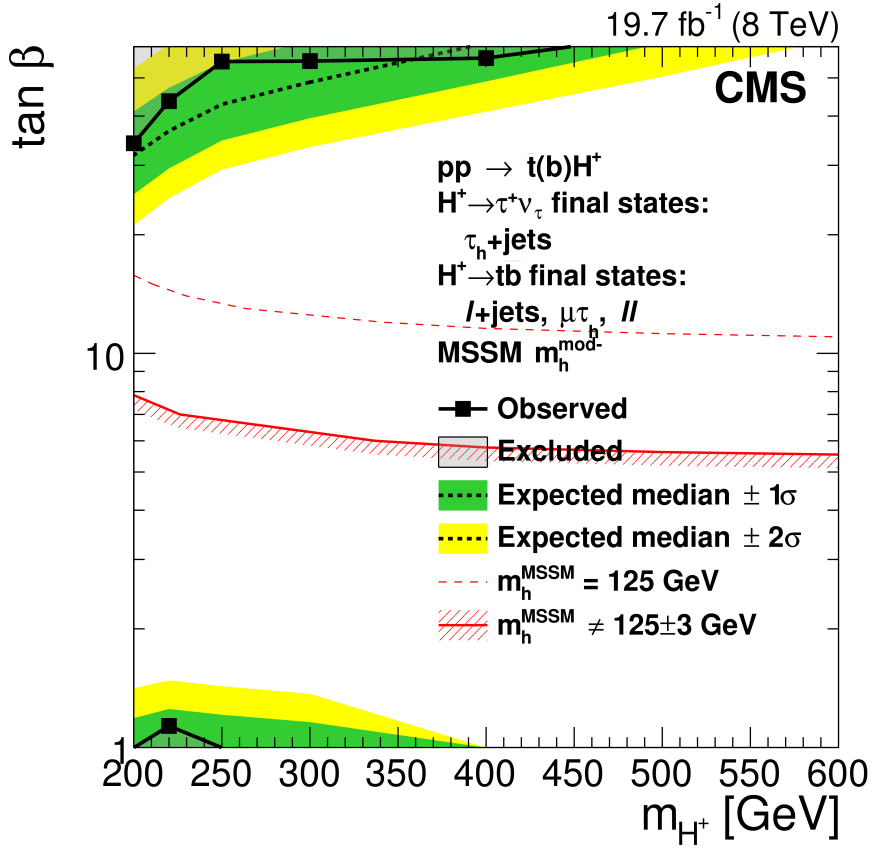
# $H^{\pm} \rightarrow \tau\nu$, tb

1508.07774
CMS, 8 TeV

- Systematic uncertainties: τ identification, b-tagging, tt modelling, ...
- 95% CL limits can be derived on cross section (x branching ratios) or in specific MSSM scenarios

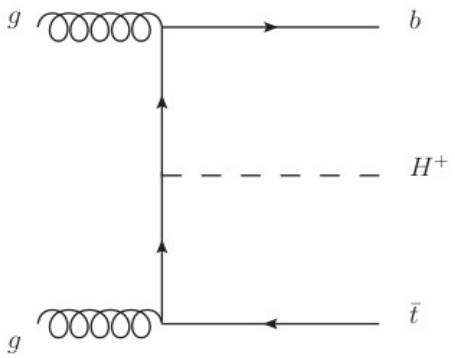



Low mass



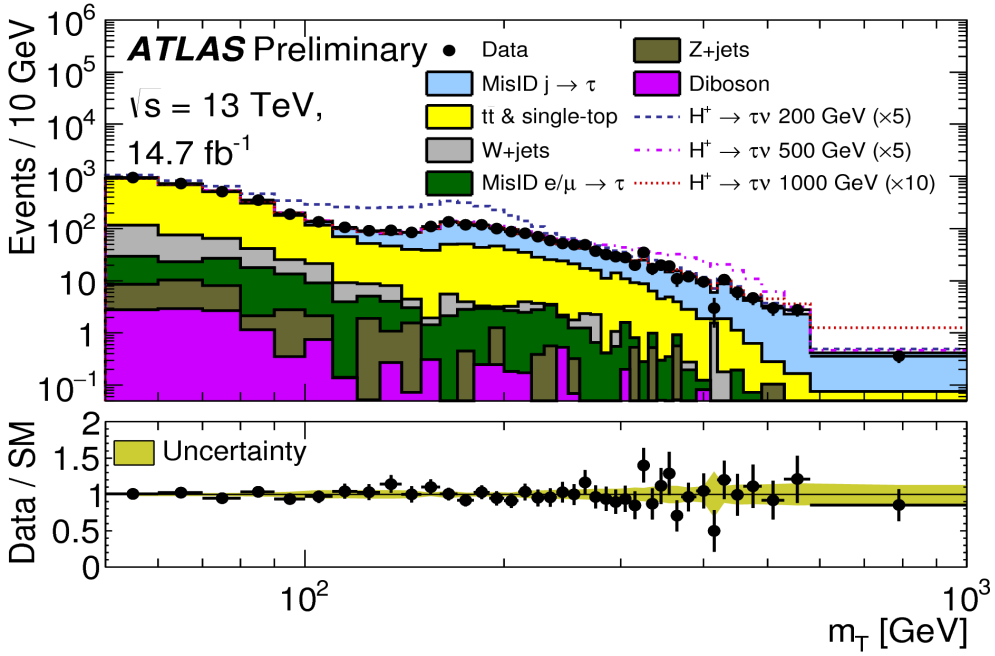

High mass

- Production of $H^{\pm} \rightarrow \tau\nu$ in association with top



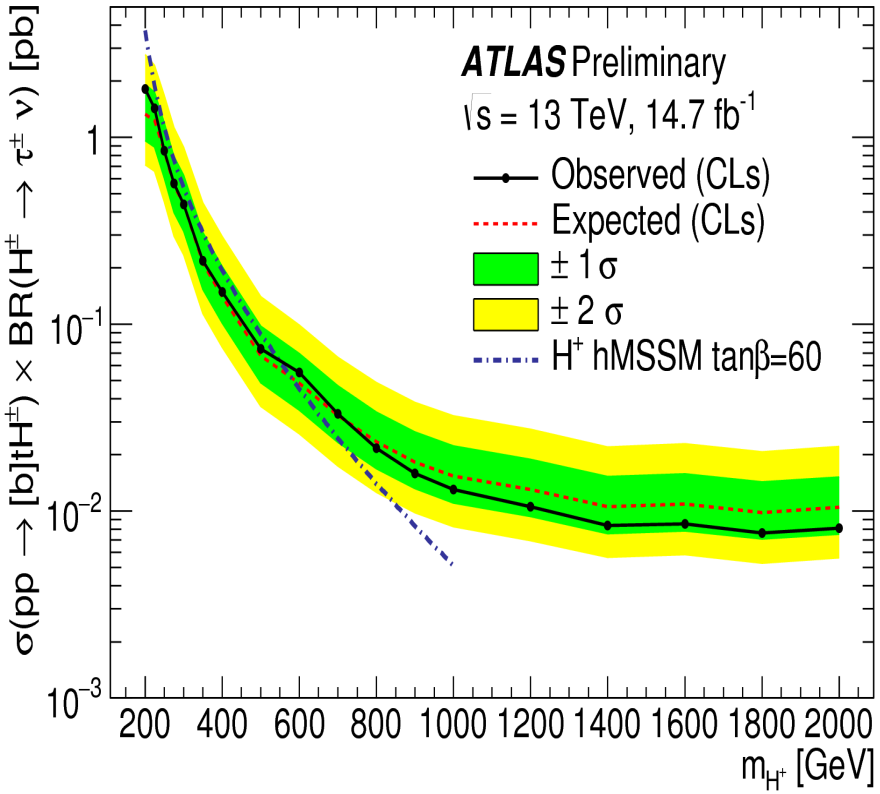

1 hadronically decaying $\tau_{\text{had-vis}}$
≥3 jets with ≥ 1 b-tag
MET > 150 GeV

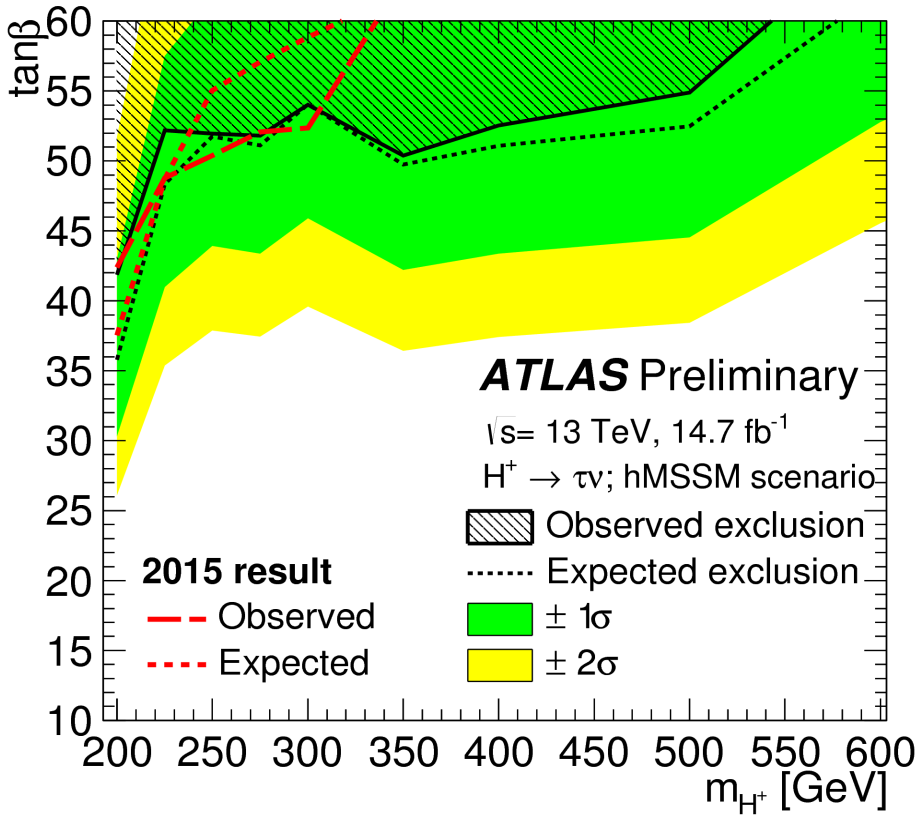
- Discriminating variable: $m_T$ of $\tau_{\text{had-vis}}$ and MET system




Data-driven background estimation for jets and e/μ identified as τ
by applying fake factors derived from control regions

- Systematic uncertainties: τ identification, b-tagging, energy scale of jets and τ, ...
- Limits on cross section x branching ratio, and interpretation in MSSM context

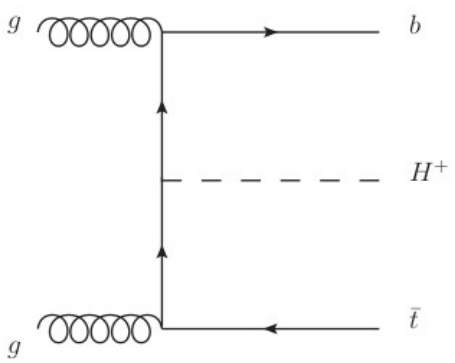


# $H^{\pm} \rightarrow tb$



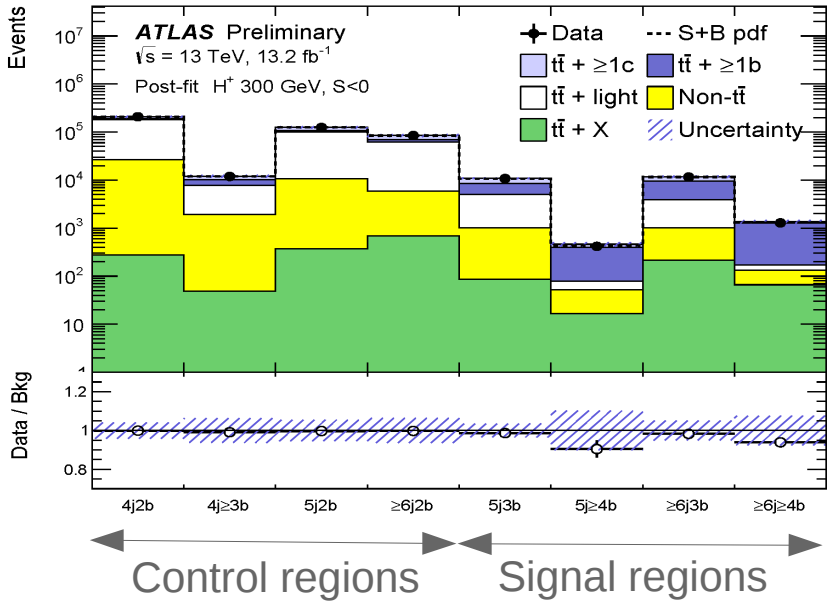
- Production of $H^{\pm} \rightarrow tb$ in association with top

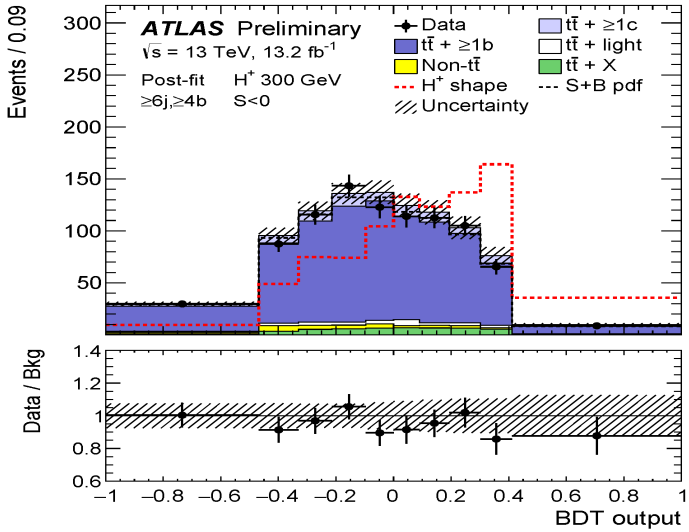



1 lepton (electron or muon)
≥4 jets with ≥2 b-tag
Veto events with $\tau_{had}$

4 control regions, 4 signal regions; based on number of jets and b-tagged jets

- Discriminating variable in signal region: BDT (leading jet $p_T$, mass of bb pair, $\Delta R$(lep, bb pair), mass of jet triplet with largest $p_T$, ...)

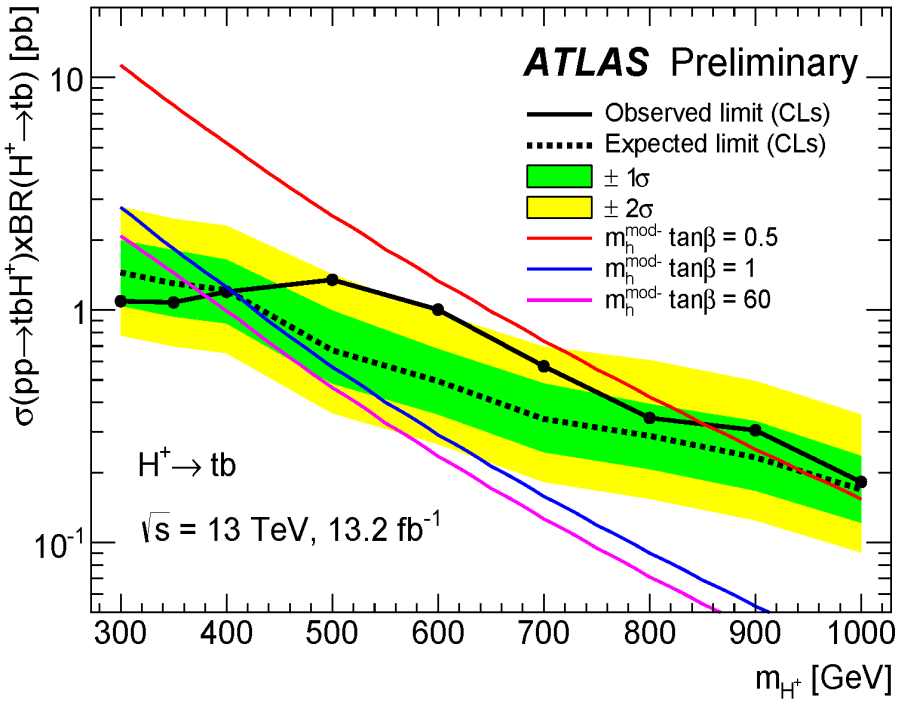


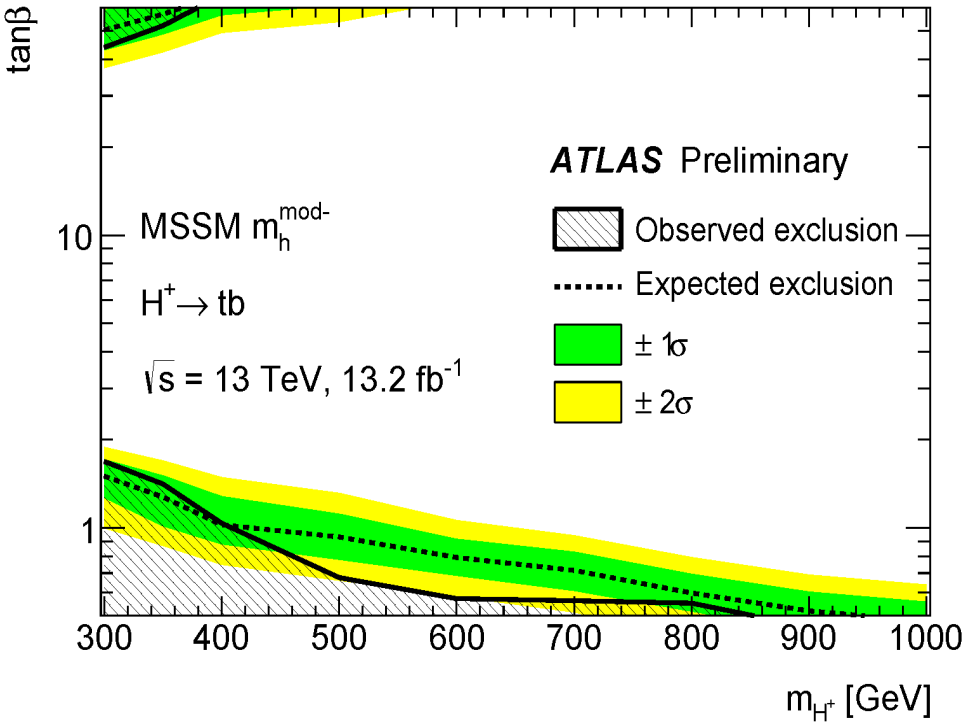



# $H^{\pm} \rightarrow tb$



- Systematic uncertainties: tt + ≥1 b/c modelling, jet flavour tagging, background model statistics, jet energy scale, ...
- Limits on cross section x branching ratio, and interpretation in MSSM context

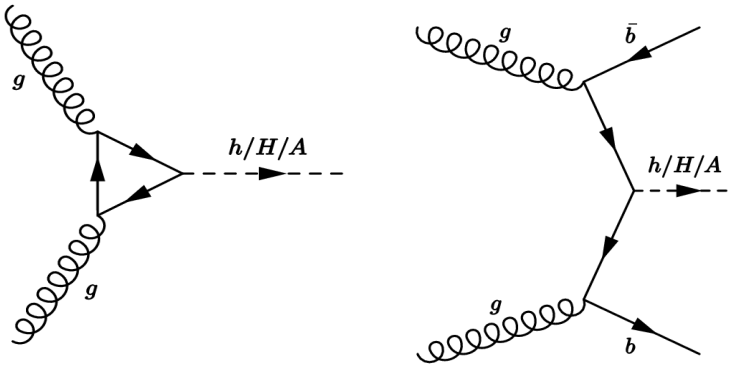


# H/A → ττ

CONF-2016-085
ATLAS, 13 TeV

> Gluon fusion and b-associated production

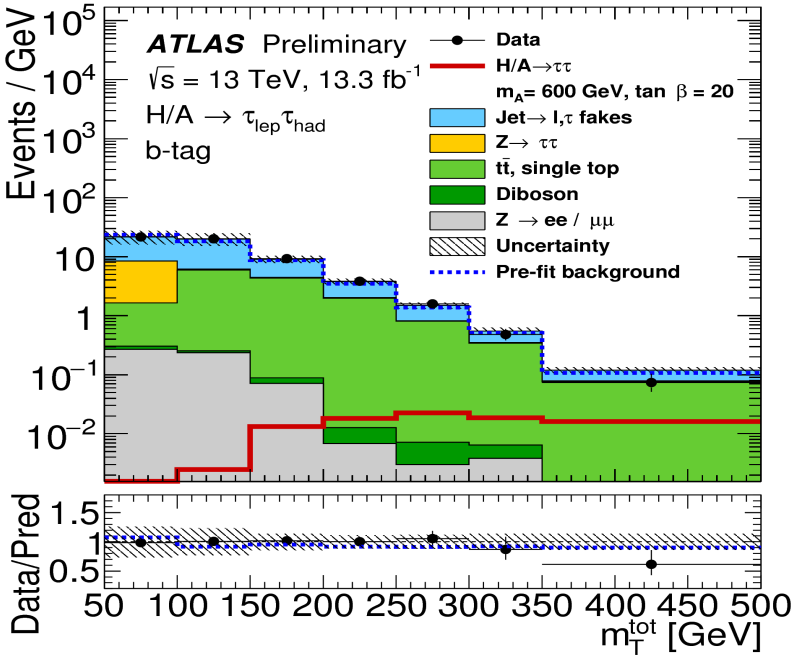


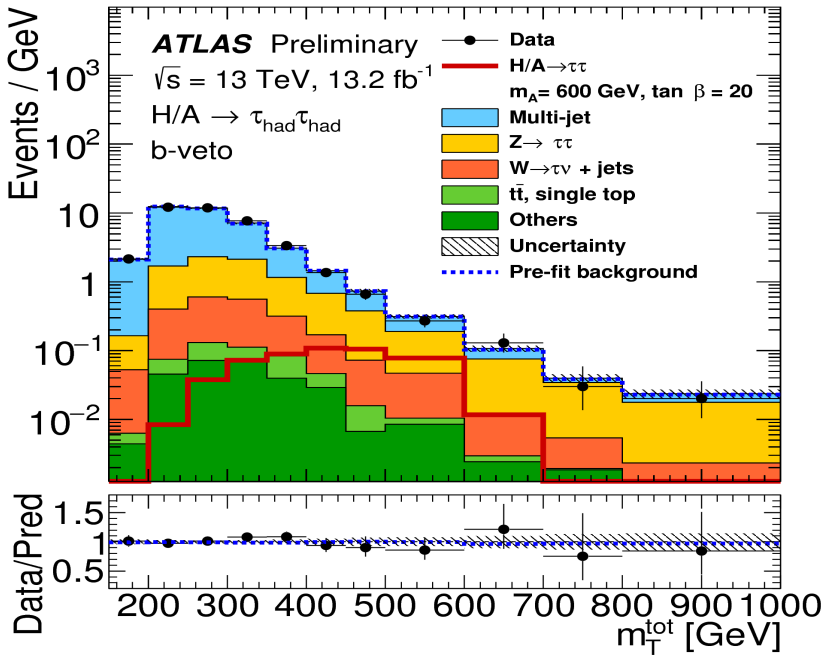

**$\tau_{lep}\tau_{had}$ channel**: 1 $\tau_{had\text{-}vis}$ and 1 lepton

**$\tau_{had}\tau_{had}$ channel**: 2 $\tau_{had\text{-}vis}$

- angular and mass cuts for W/Z background removal
- event categories according to presence of b-tagged jets

> Discriminating variable: **transverse mass of di-tau system**



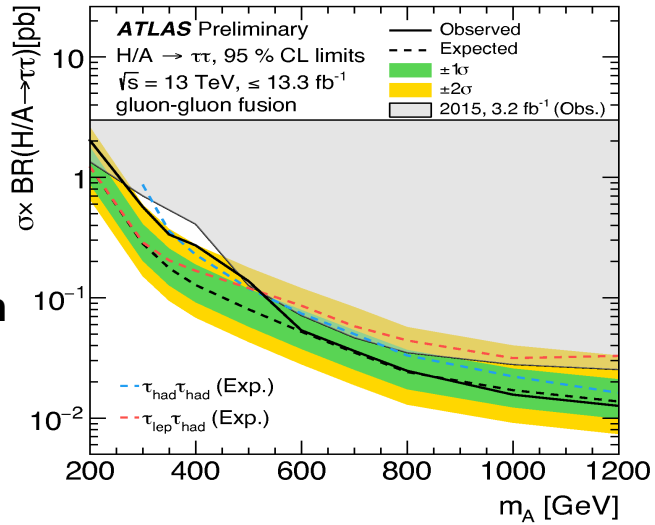



# H/A → ττ

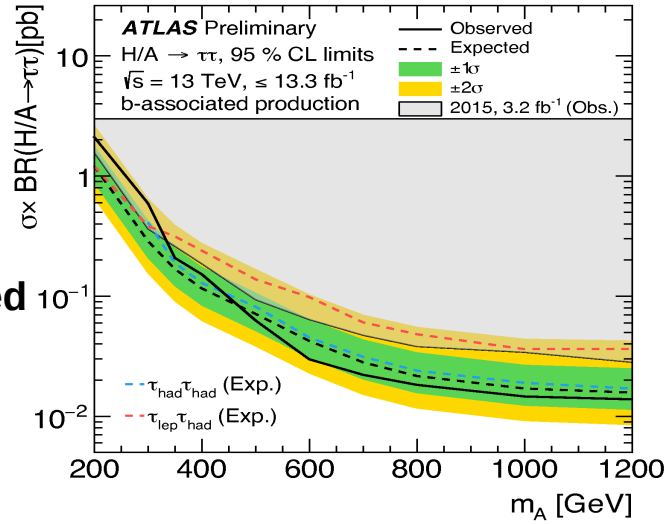


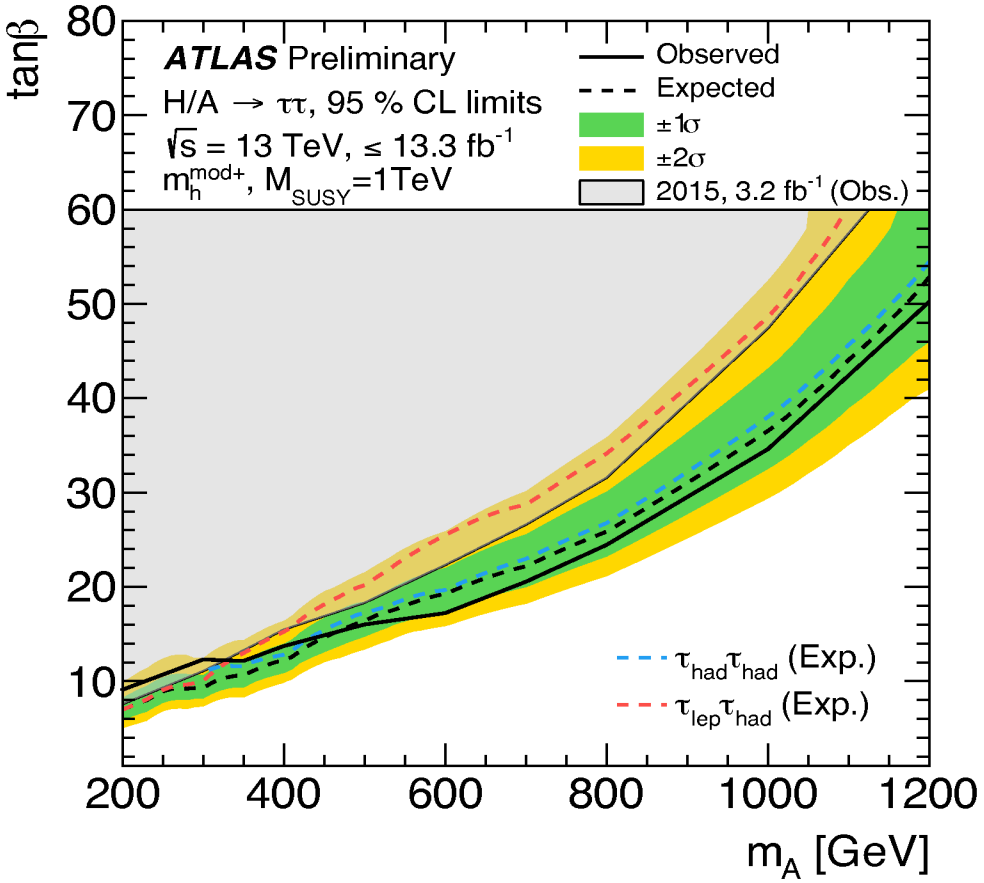
> Systematic uncertainties: top background parton shower modelling, $\tau_{had}$ energy scale, multijet estimation, ...

b-veto categories mainly sensitive to **gluon fusion**



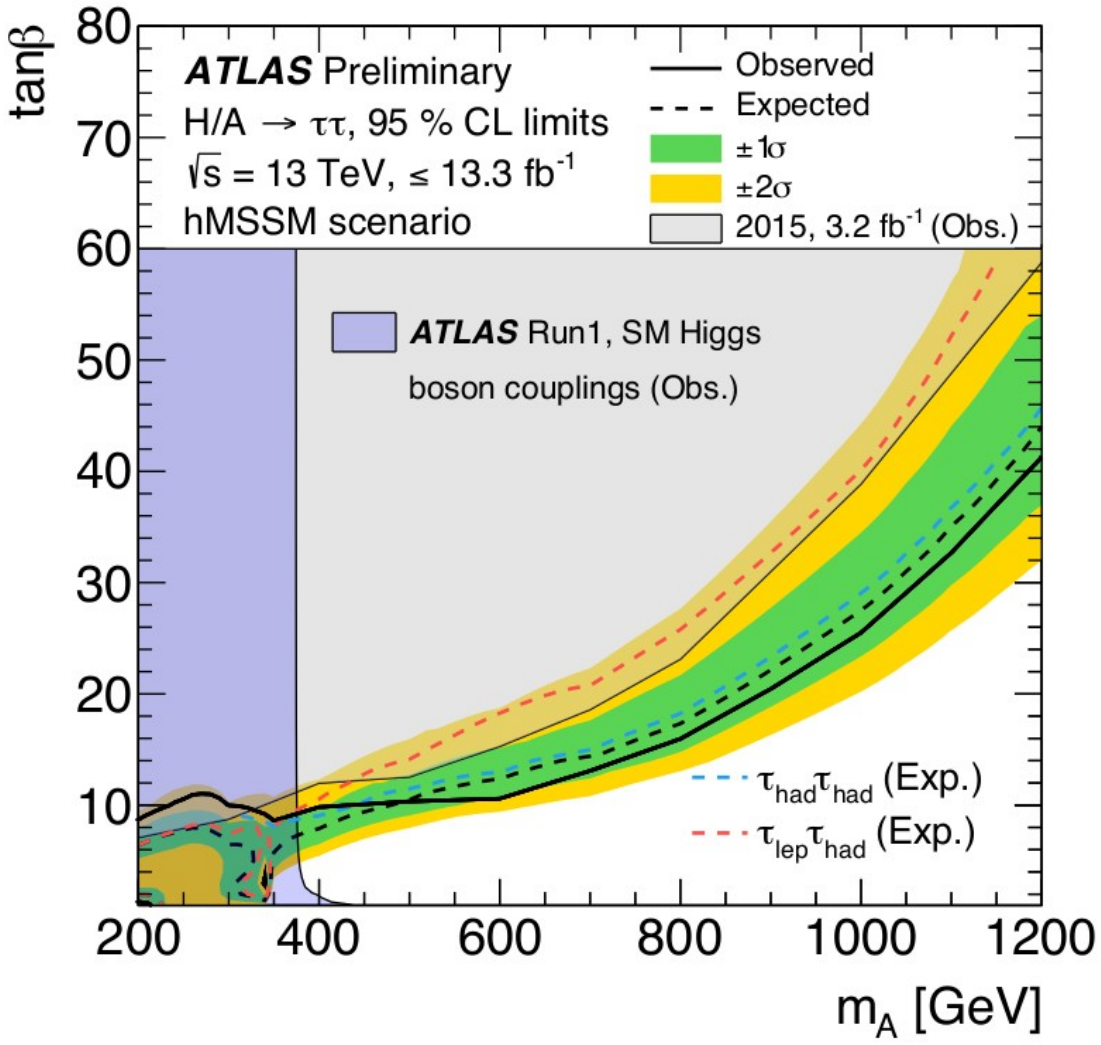

b-tag categories mainly sensitive to **b-associated production**



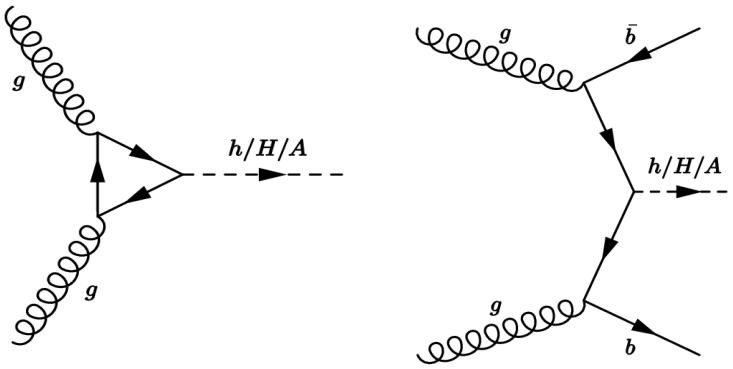




**Backup:** CMS 13 TeV HIG-16-006 excluding tan(β) > 10 at $m_A$ = 200 GeV and tan(β) > 50 at $m_A$ = 1000 GeV

> hMSSM interpretation



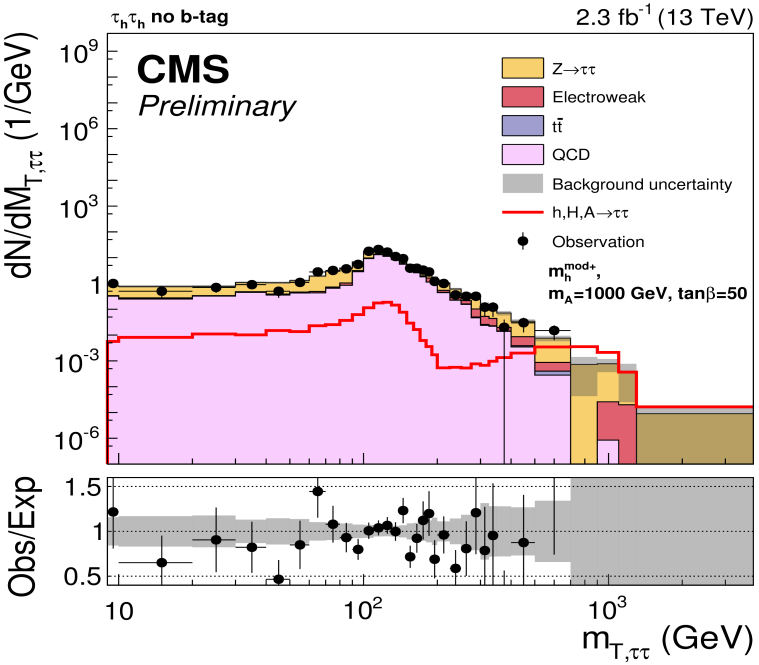
- Gluon fusion and b-associated production

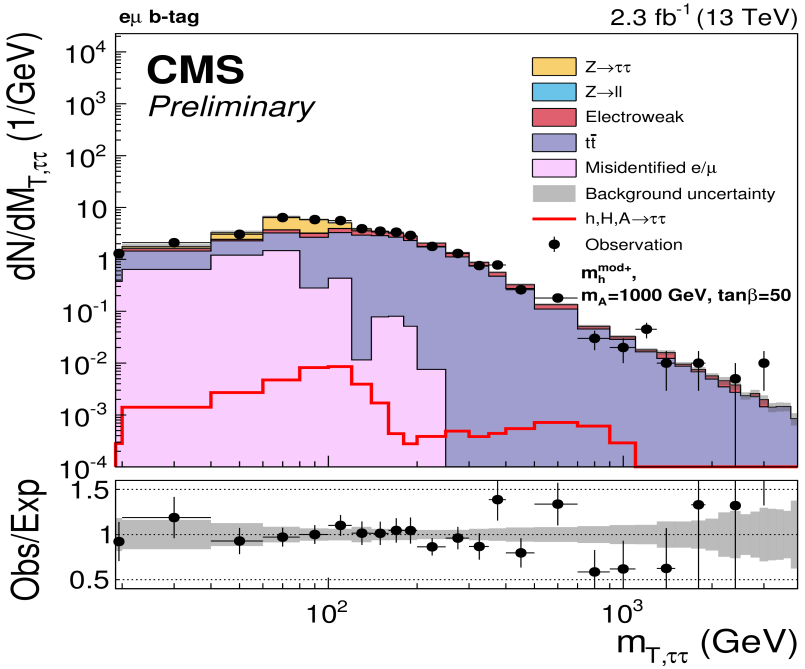



**channels:** eμ, $e\tau_{had}$, $\mu\tau_{had}$, $\tau_{had}\tau_{had}$

- transverse mass cuts for W background removal
- topological discriminator cut for tt rejection
- event categories according to presence of b-tagged jets

- Discriminating variable: transverse mass of di-tau system

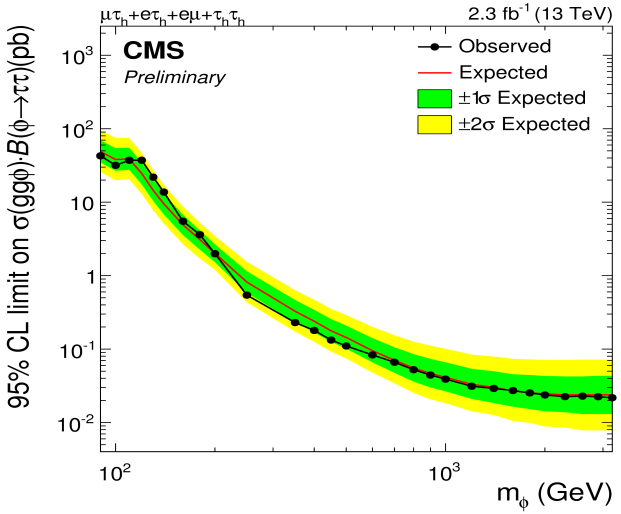


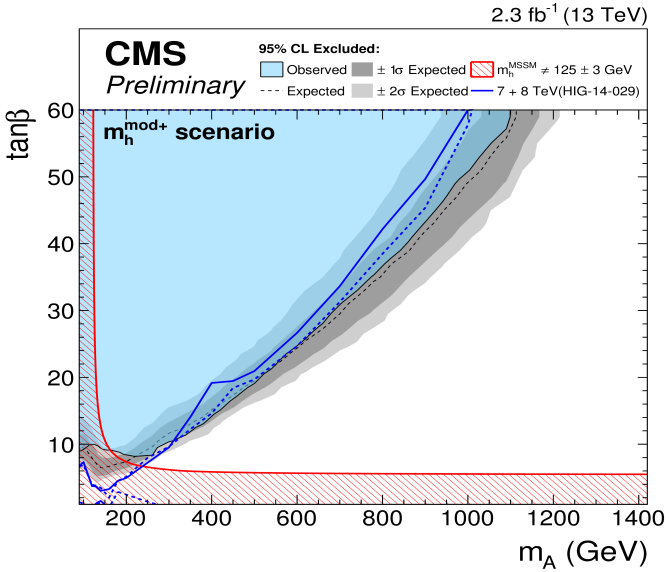



# H/A → ττ

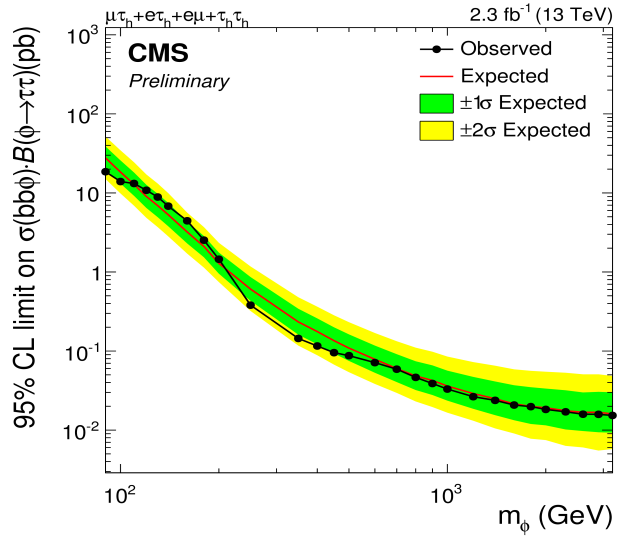
- Systematic uncertainties: top background normalizations, $\tau_{had}$ mis-identification rate, τ trigger, ...

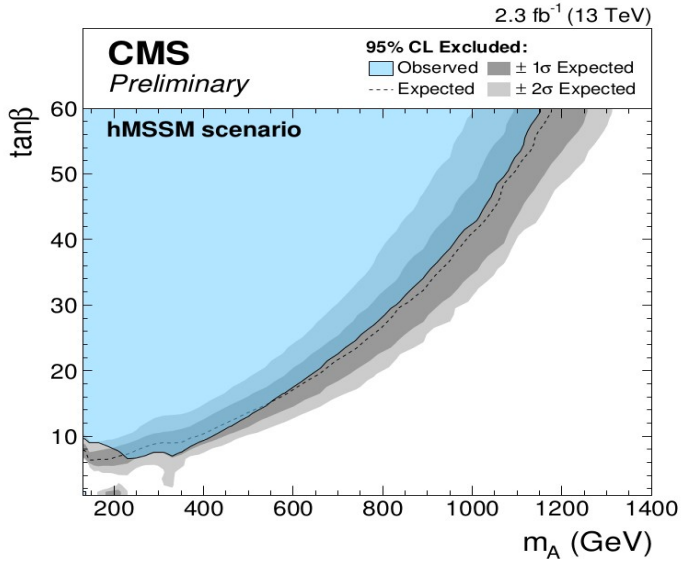
**b-veto** categories mainly sensitive to **gluon fusion**




**b-tag** categories mainly sensitive to **b-associated production**

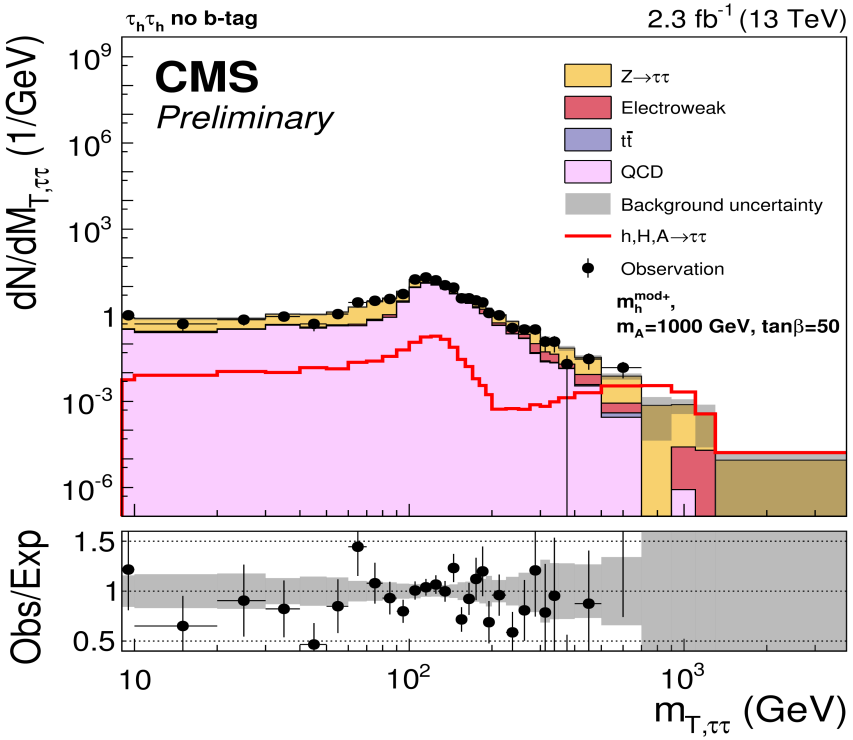


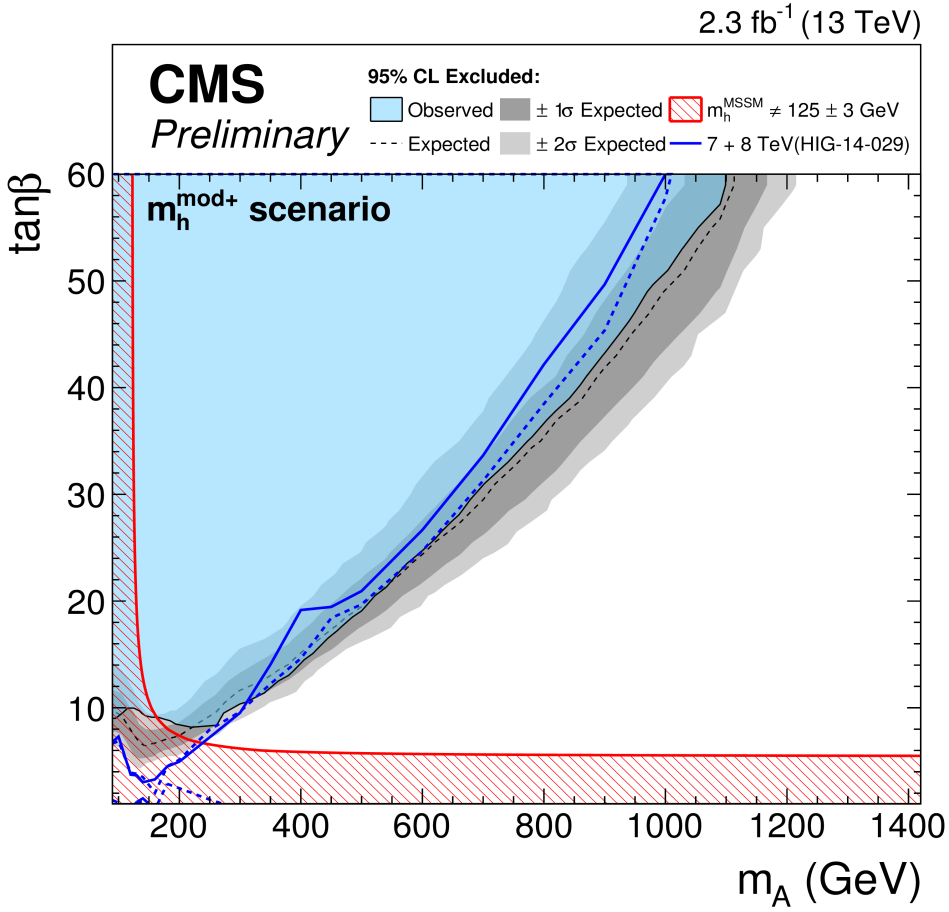



# H/A → ττ



- Channels: eμ, $e\tau_{had}$, $\mu\tau_{had}$, $\tau_{had}\tau_{had}$
- Selections targeting gluon fusion and b-associated production (0 or ≥1 b jet)
- Discriminating variable: transverse mass di-tau system



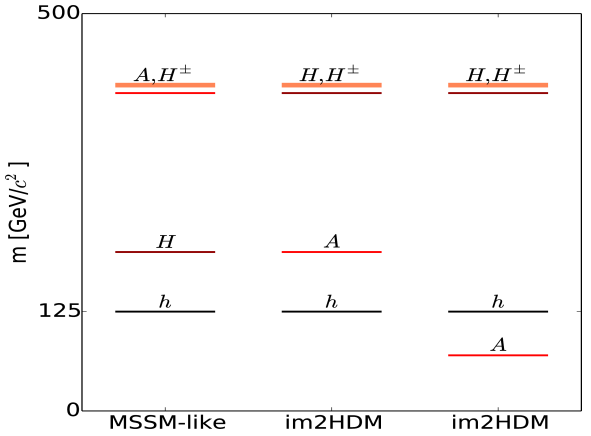



# H → ZA

HIG-16-010
CMS, 13 TeV

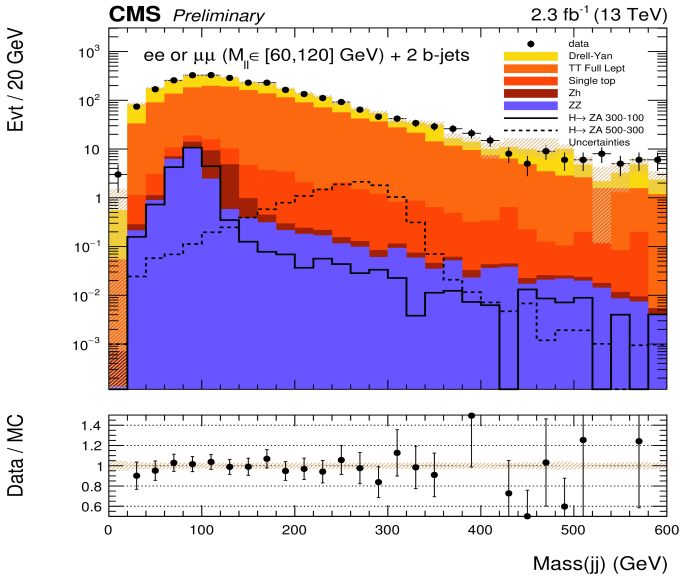
- Mass hierarchy might allow decay of one new Higgs boson to another
- Consider decay of H to Z (decaying to 2 leptons) and A (decaying to 2 b quarks)

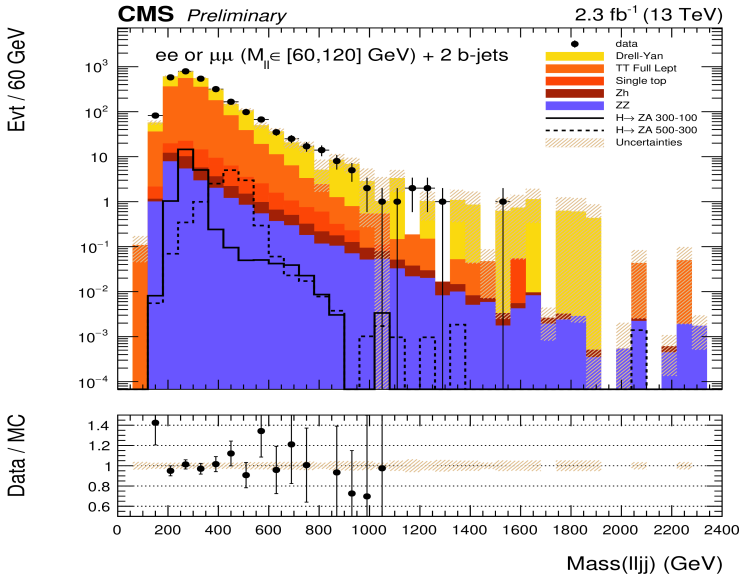
  2 OSSF leptons
  ≥2 b-tagged jets




im = “Inverted mass hierarchy”

- Depending on ($m_H$, $m_A$) hypothesis, consider rectangular signal region in ($m_{llbb}$, $m_{bb}$) plane and use inverse as control region



# A → Zh

CONF-2016-015
ATLAS, 13 TeV

- Assumed decay of pseudoscalar A to Z boson and SM Higgs boson h
- Channels targeted: Z → ee, μμ, νν and H → bb

  **Categories** according to

  #charged leptons (0 or 2)

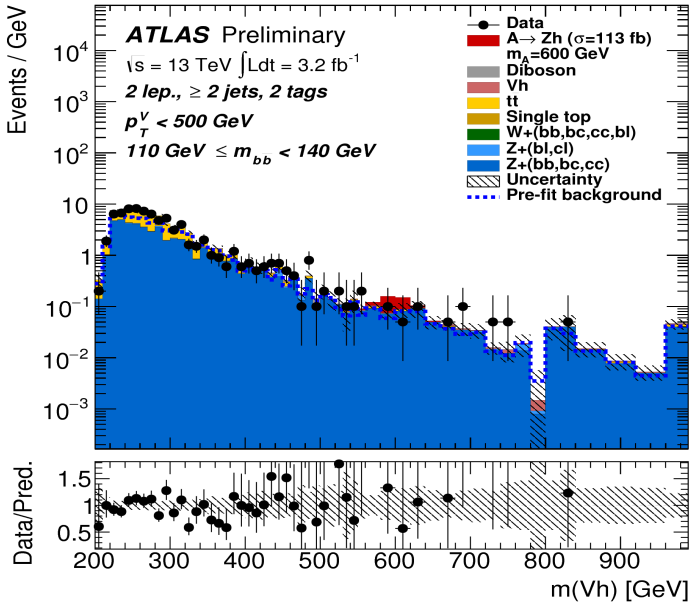
  $p_T$ of Z candidate (low < 500 GeV, high ≥ 500 GeV)

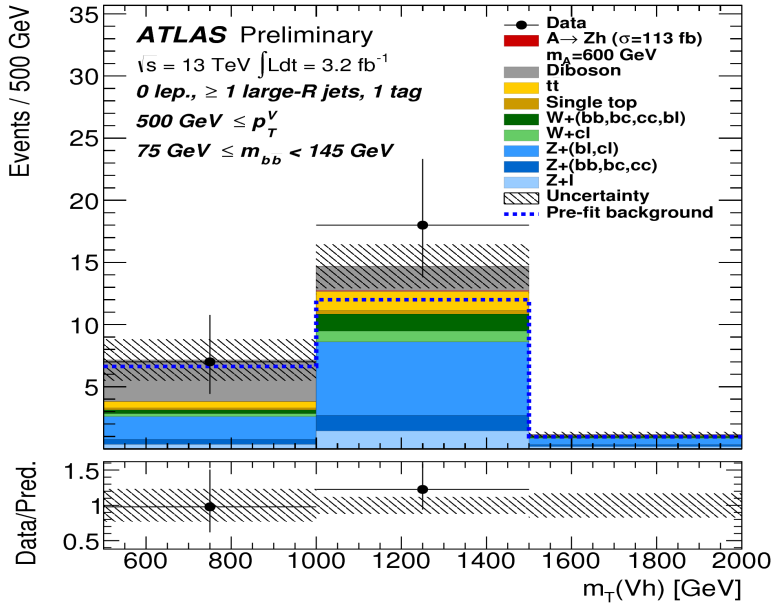
  #b-tagged jets (1 or 2)

  Requiring ≥1 *large-R* jet in high-$p_T$ Z categories

  Requirements of dilepton mass and (di)jet mass: compatibility with Z and h

- Discriminating variable: mass in 2-lep, transverse mass in 0-lep categories

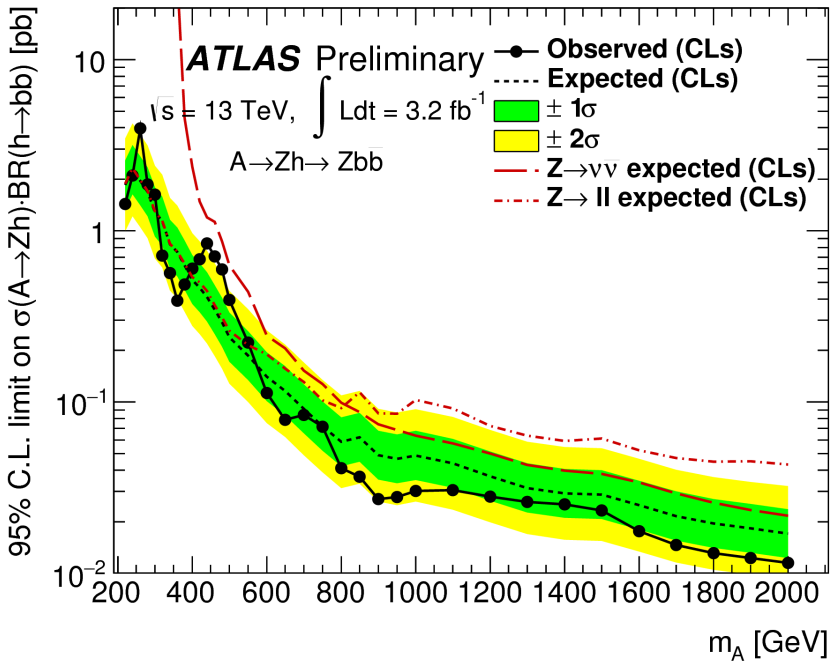


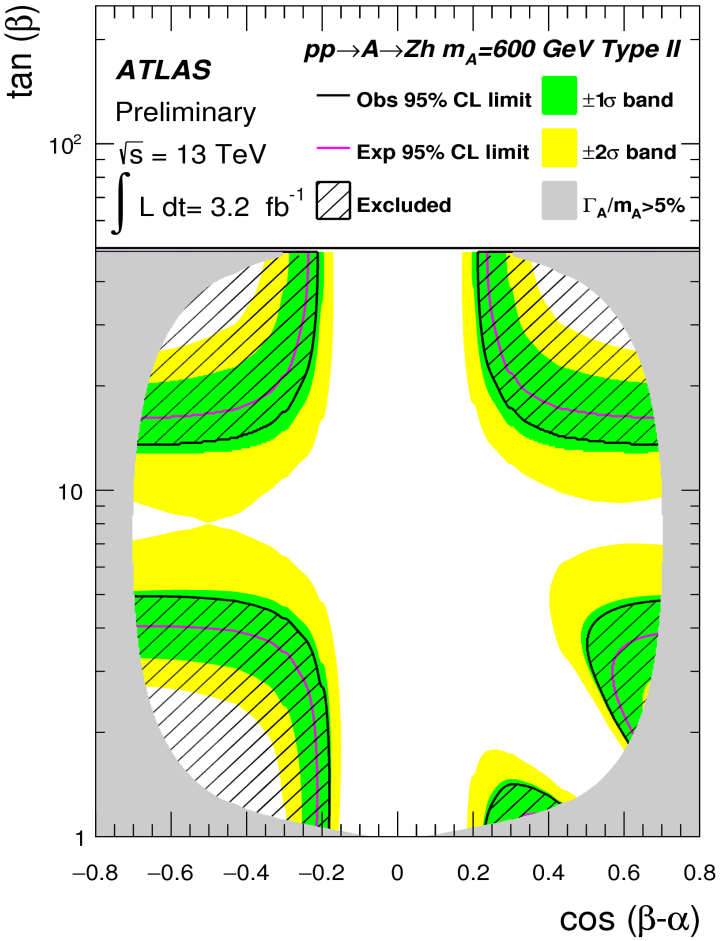



# A → Zh

CONF-2016-015
ATLAS, 13 TeV

- Systematic uncertainties: jet energy scale and resolution, large-R jet mass, b-tagging, ...
- Limits on gluon fusion or b-associated production cross sections x BR, or interpretation in 2HDM parameter space



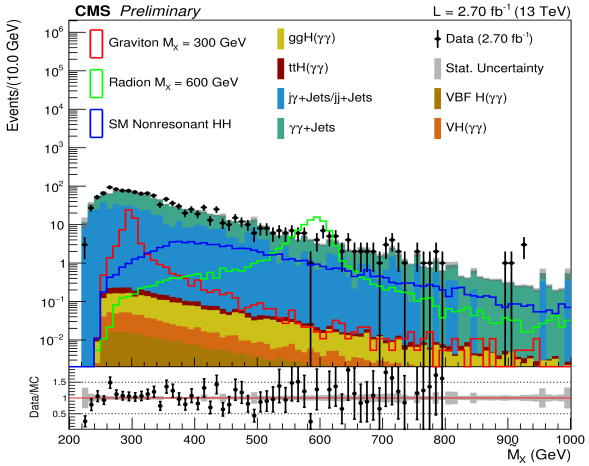
# H → hh

HIG-16-032
CMS, 13 TeV

> Search for resonant production of two SM-like h bosons (hh → bbγγ)

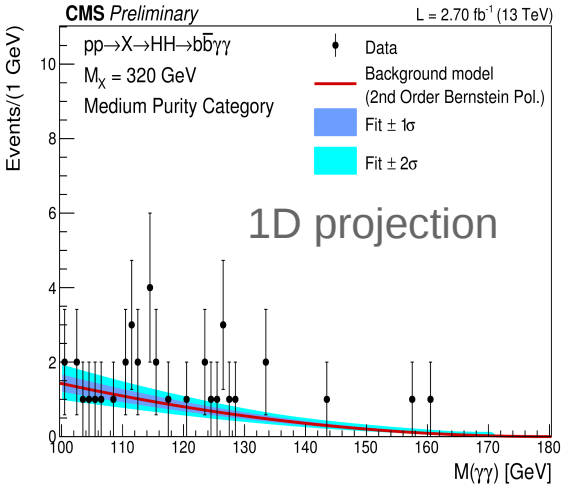
≥2 photon candidates
dijet candidate (2 jets with highest b-tag scores)

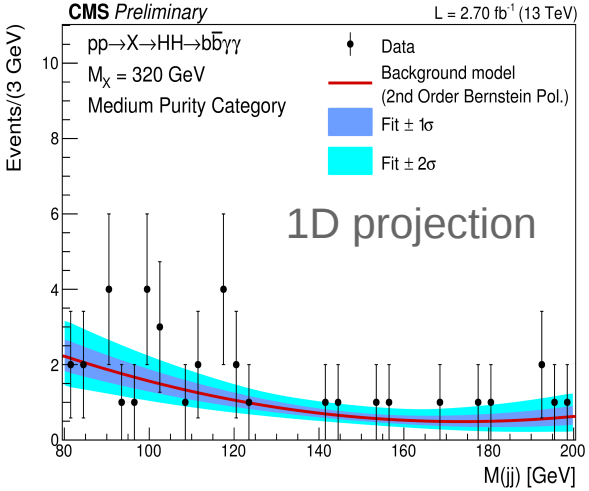
resonance search: window of mass(jjγγ)
depending on signal hypothesis

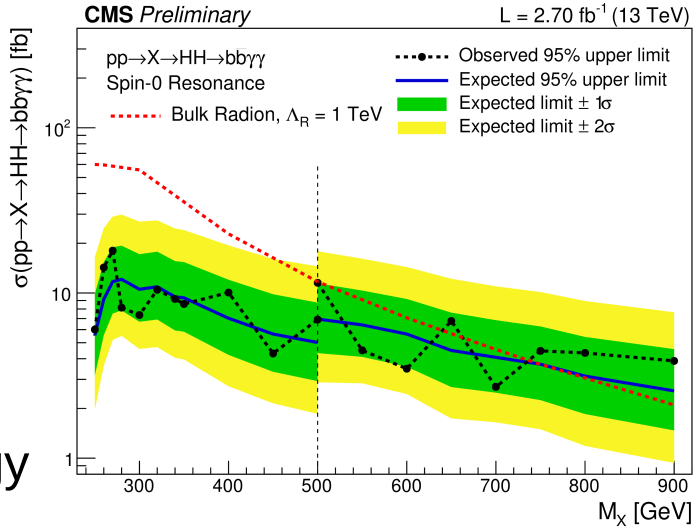



$M_X = M(jj\gamma\gamma) - M(jj) + 125\ GeV$

> Parametric fit of 2D plane defined by diphoton and dijet mass




> Systematic uncertainties: jet and photon energy scales and resolutions, b-tagging efficiency, ...

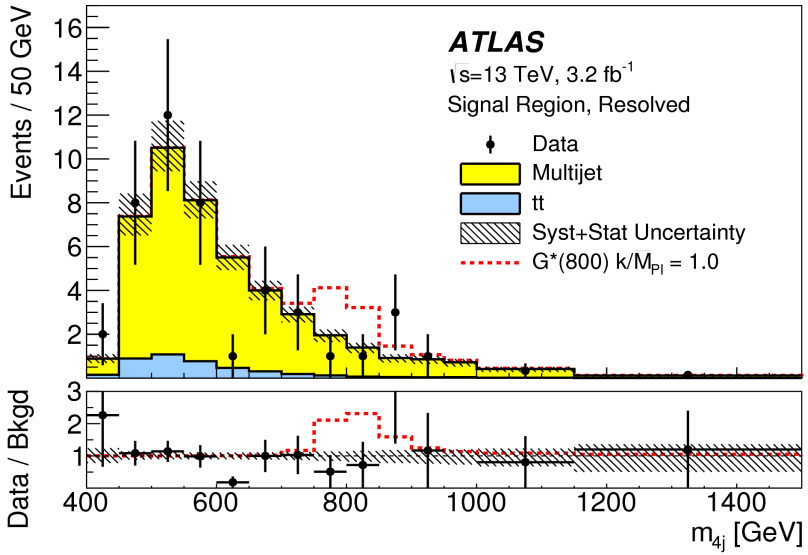
# H→hh

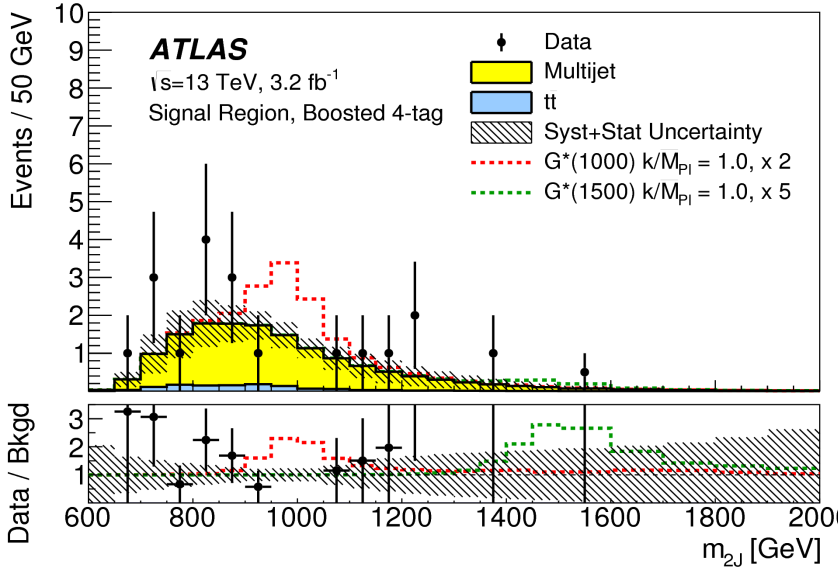
1606.04782
ATLAS, 13 TeV

- Search for resonant production of two SM-like h bosons (h→bb)
  - **"Resolved" regime** up to resonance mass 1.1 TeV

    ≥ 4 b-tagged jets
    forming 2 dijet systems with small ΔR
    $m_{4jet}$ dependent $p_T$ requirements on dijets
  - **"Boosted" regime** above 1.1 TeV

    3 or 4 b-tagged jets
    ≥ 2 large-R jets with ≥ 2 smaller-R track jets associated to each
- Discriminating variables: reconstructed resonance mass

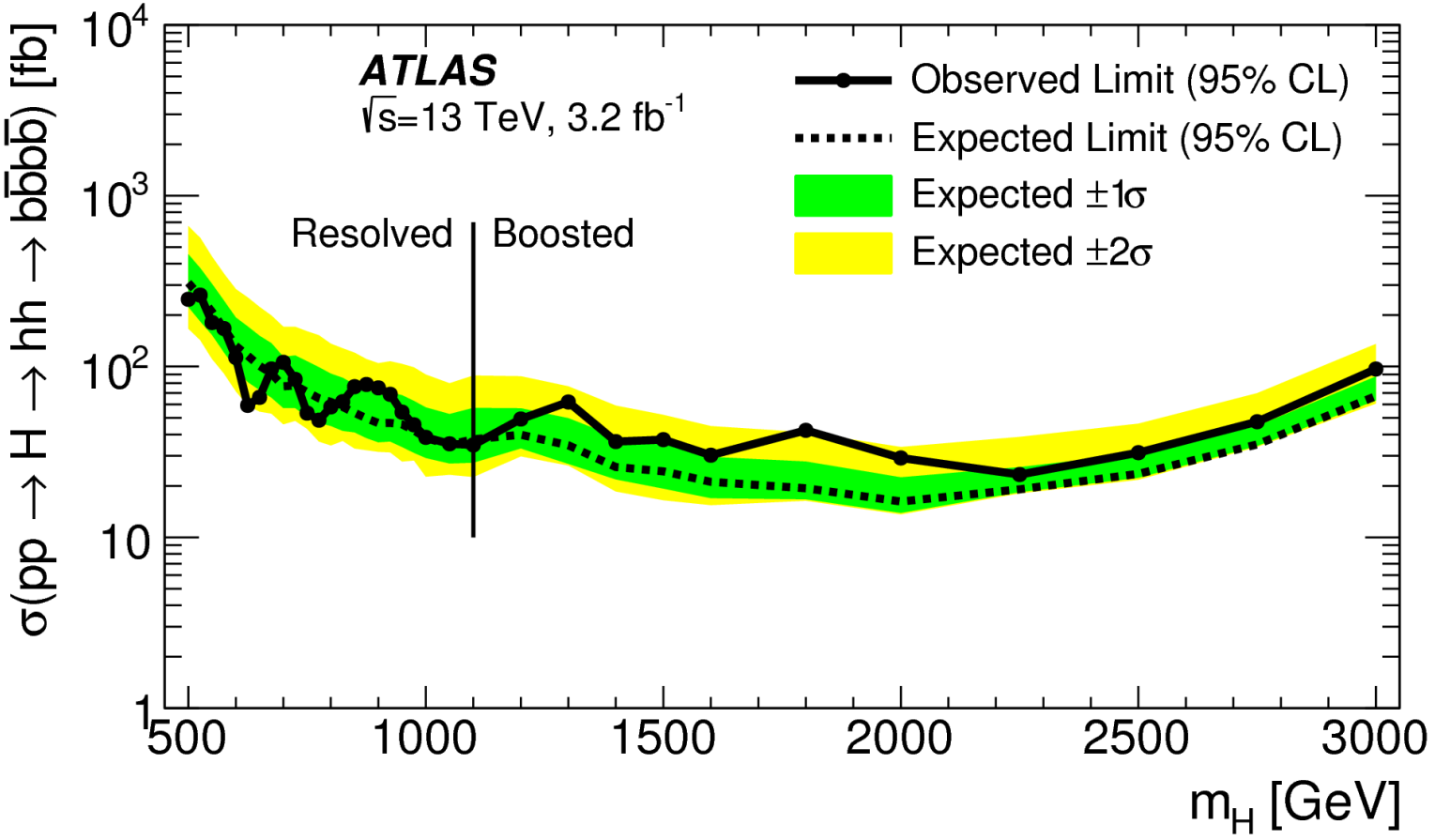


# H → hh

1606.04782
ATLAS, 13 TeV

- Systematic uncertainties: b-tagging, multijet background, large-R jet-mass scale and resolution, …
- Interpretation as new narrow-width Higgs resonance

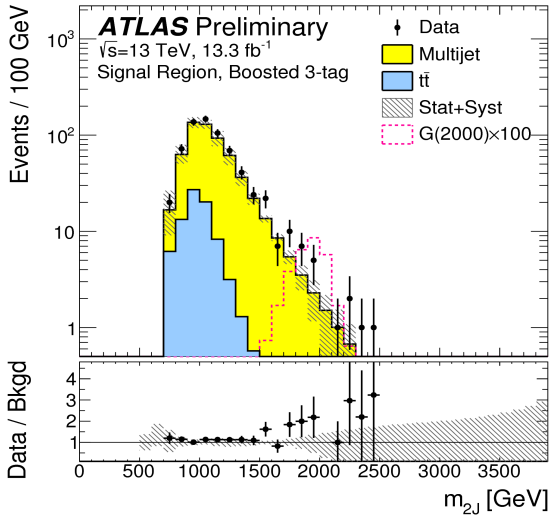


# H→hh

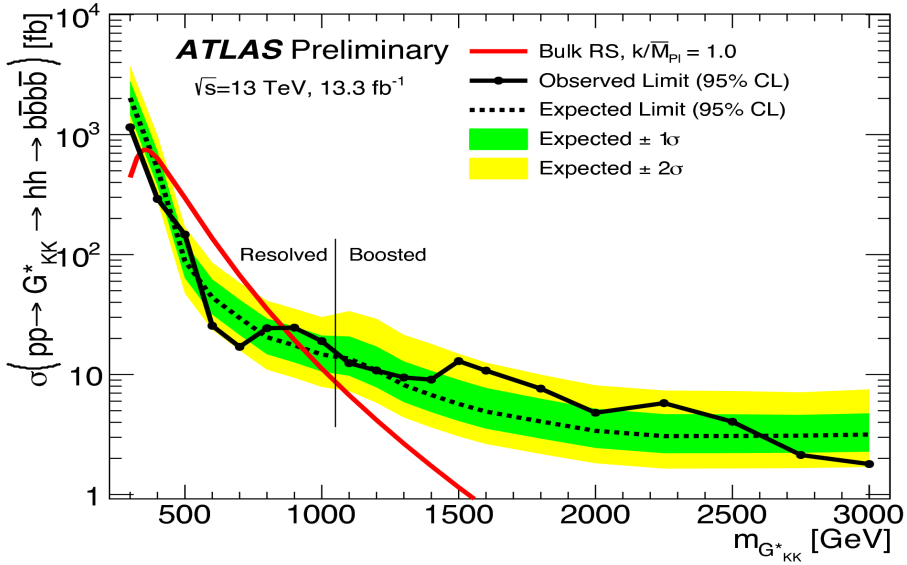
CONF-2016-049
ATLAS, 13 TeV

- Resonant production of two SM-like h bosons (h→bb)
  - **"Resolved" regime**
    ≥4 b-tagged jets
    forming 2 dijet systems with small ΔR
    $m_{4jet}$ dependent $p_T$ requirements on dijets
  - **"Boosted" regime**
    2, 3 or 4 b-tagged jets
    ≥2 large-R jets with ≥1 smaller-R b-tagged track jets associated to each

Reconstructed resonance mass in boosted regime




- Systematics: b-tagging, multijet background, large-R jet mass scale and resolution
- Interpretation in spin-2 KK graviton resonance context



# H→WW/ZZ

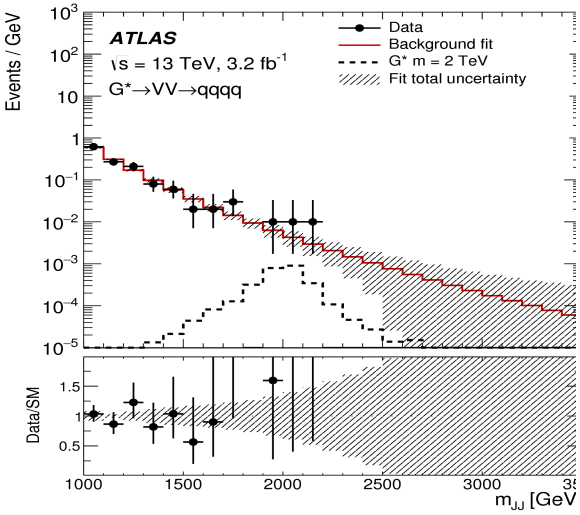
1606.04883
ATLAS, 13 TeV

- Relevant channels: qqqq, ννqq, llqq

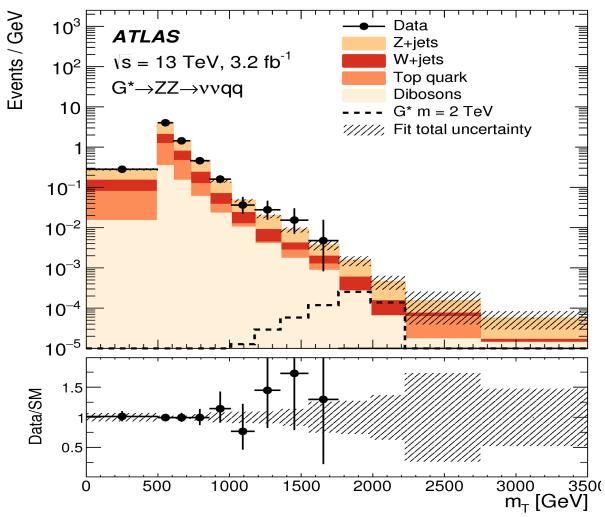
  ≥1 large-R jet, $p_T$ > 200 GeV, mass > 50 GeV

  no leptons, MET > 250 GeV → ννqq
  no leptons, MET < 250 GeV, additional large-R jet → qqqq
  2 (OS)SF leptons in Z window → llqq

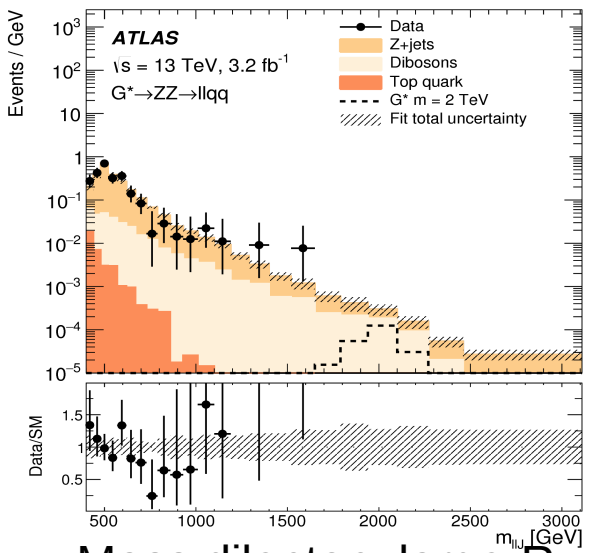
- Dominant backgrounds: multijet (qqqq) modelled as smoothly falling $m_{JJ}$ spectrum, Z+jets (ννqq and llqq) from control region




Mass large-R jets system (qqqq)




Transverse mass (ννqq)

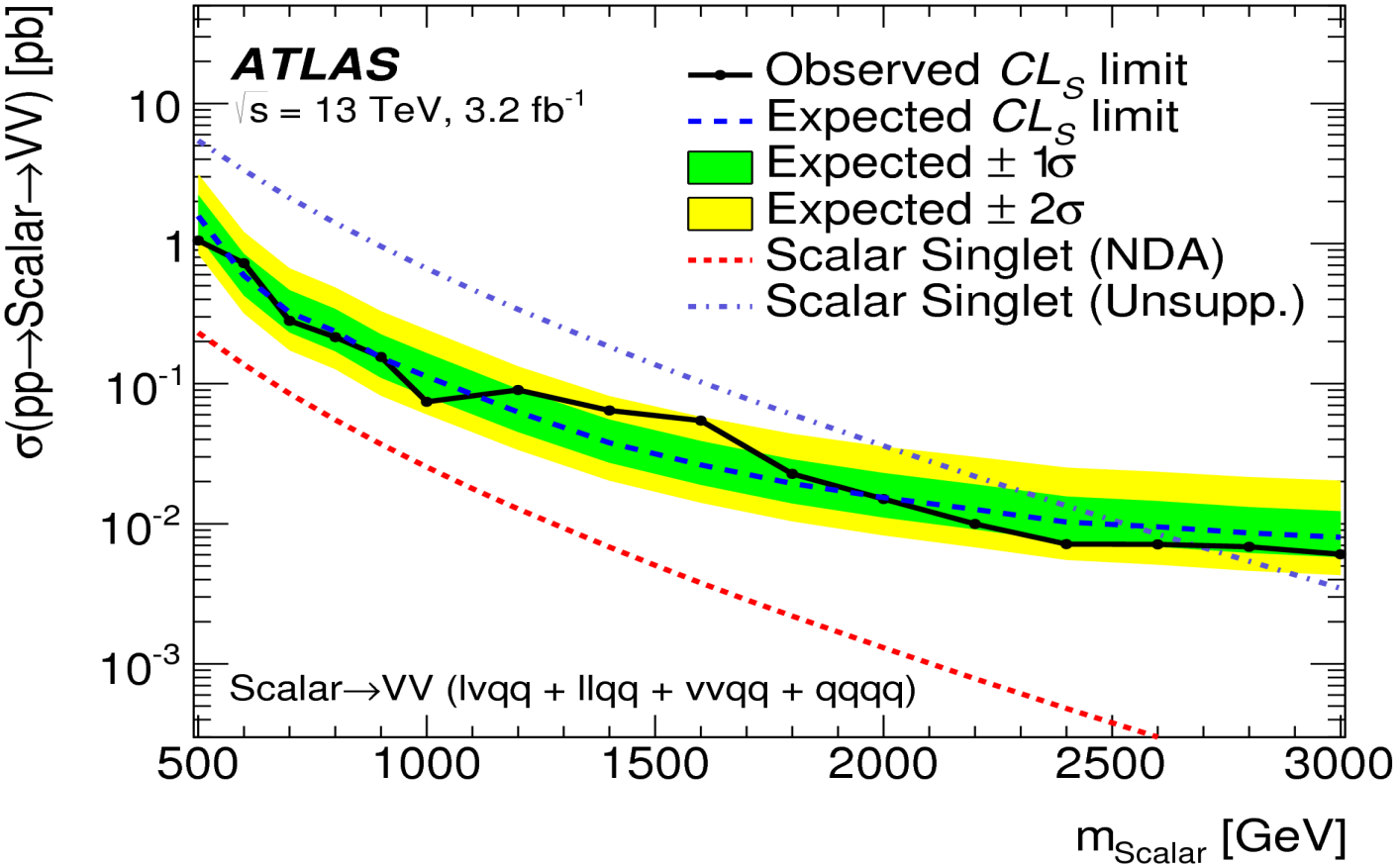



Mass dilepton, large-R jet system (llqq)

# H→WW/ZZ

1606.04883
ATLAS, 13 TeV

- Systematic uncertainties: large-R jet energy/mass scale and resolution, lepton energy scale, theoretical uncertainties of tt and diboson, …
- Interpretation as narrow-width scalar singlet



> 2-lepton analysis (llqq channel)

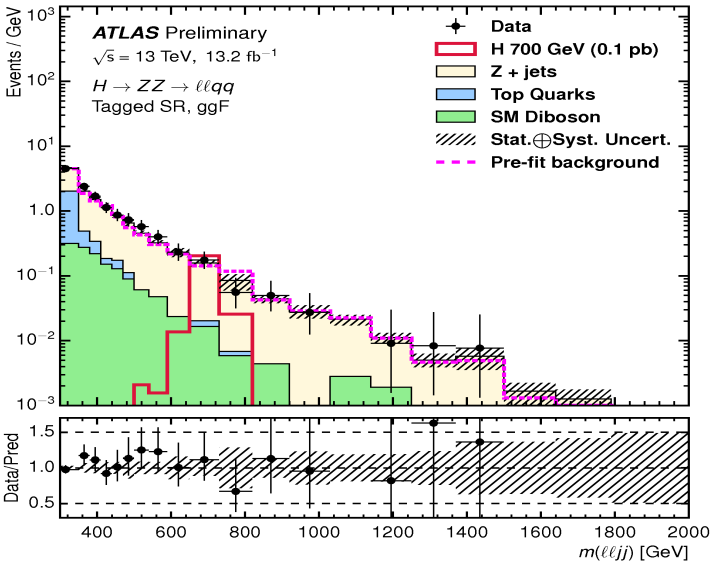
- OSSF electrons or muons in Z mass window
- large-R jet (decay products from Z merged) or ≥ 2 small-R jets (not merged) consistent with Z mass

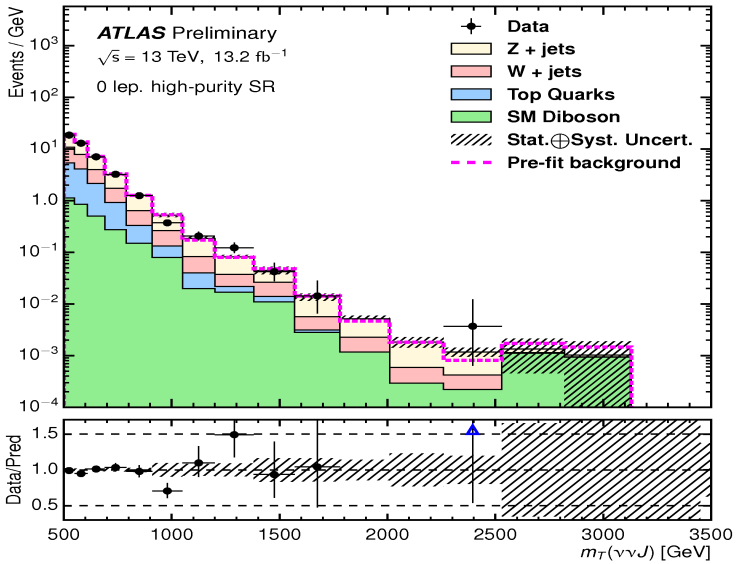
0-lepton analysis (ννqq channel)

- MET > 250 GeV, veto on leptons
- large-R jet consistent with Z mass

> Side-bands of (di)jet mass used to control the main Z/W+jets backgrounds

Discriminating variables: masses or transverse masses

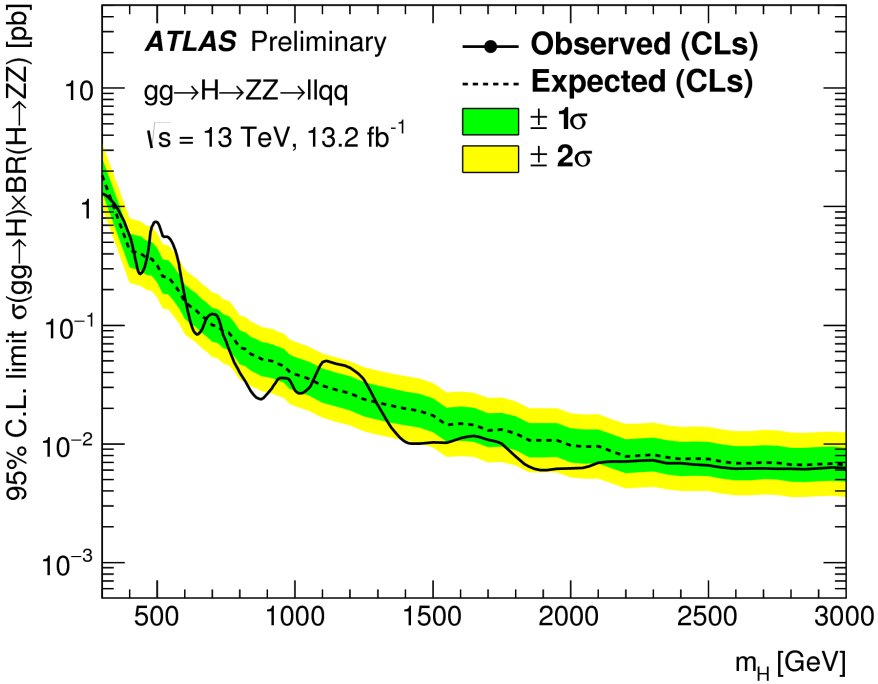


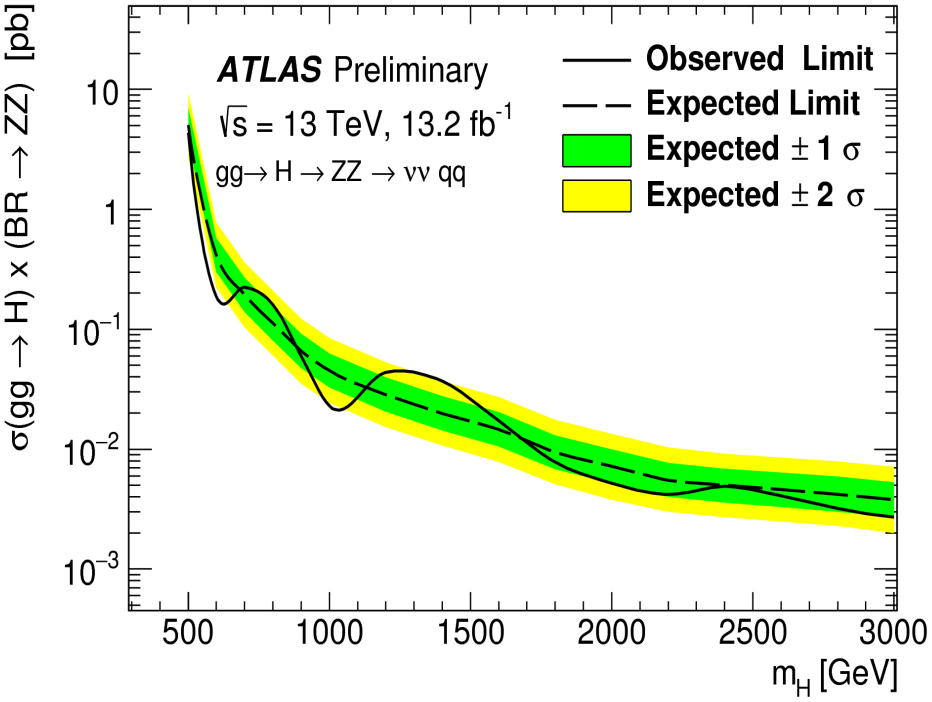
# H → ZZ

- Systematic uncertainties: large-R jet energy scale and resolution, jet structure, W/Z+jets modelling, ...
- Interpretation as new heavy scalar

2-lepton analysis

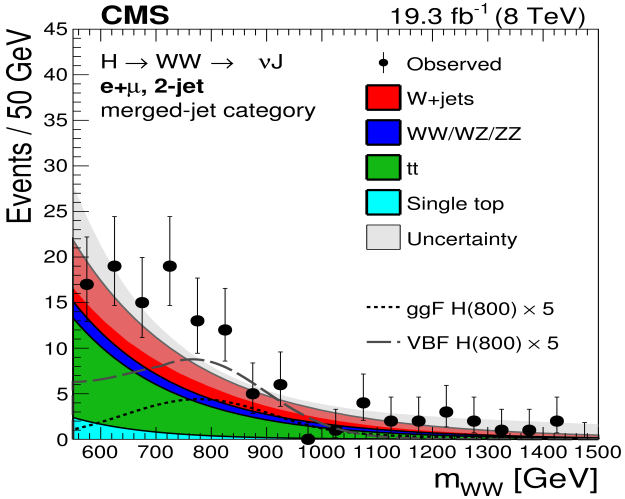



0-lepton analysis



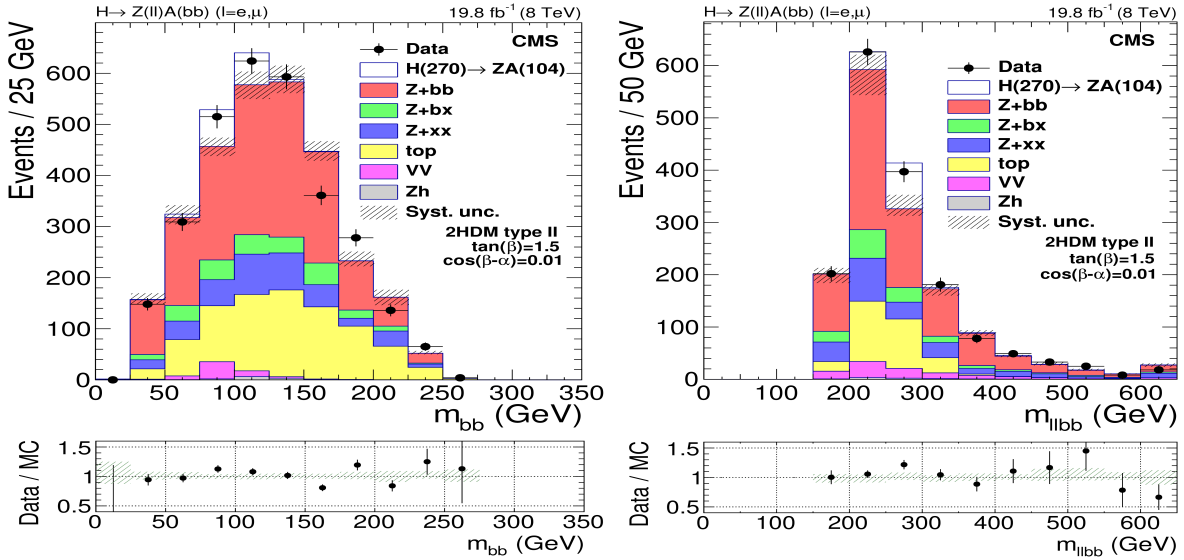
# Some moderate excesses in Run 1 (I)

- H→WW, CMS 7+8 TeV [1504.00936]




2.6σ at 700 GeV,
2.1σ at 800 GeV

- reso→Zbb, CMS 8 TeV [1603.02991]

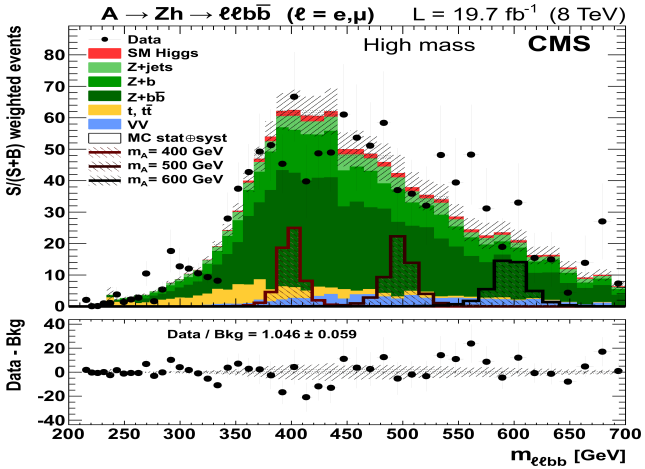


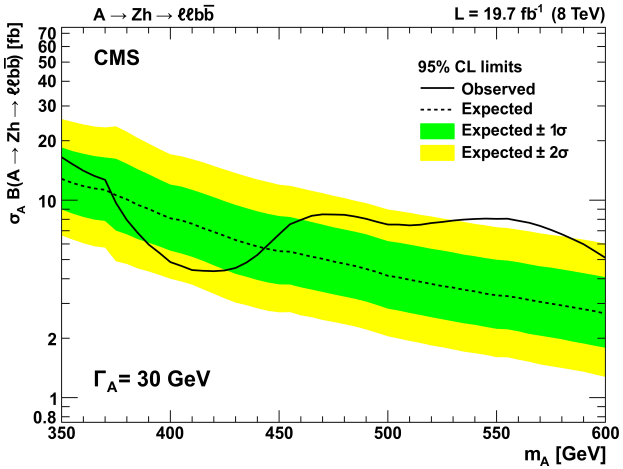

Excess most compatible with hypothesized signal:

($m_{bb}$,$m_{llbb}$) = (95,285) GeV
at 2.6σ local (1.6σ global)

# Some moderate excesses in Run 1 (II)

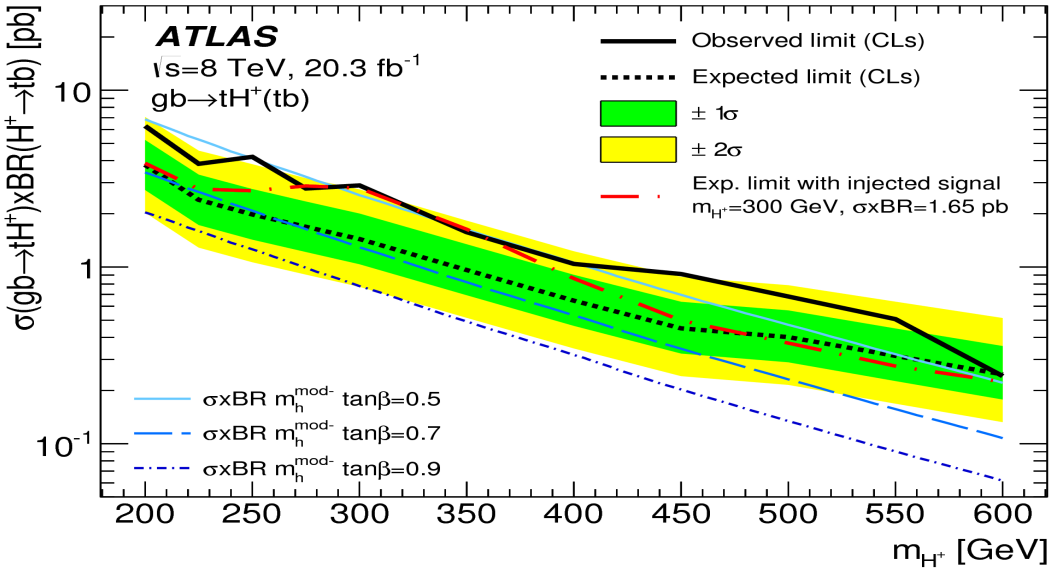
> A→Zh, CMS 8 TeV [1504.04710]




2.6σ local (1.1σ global) at 560 GeV

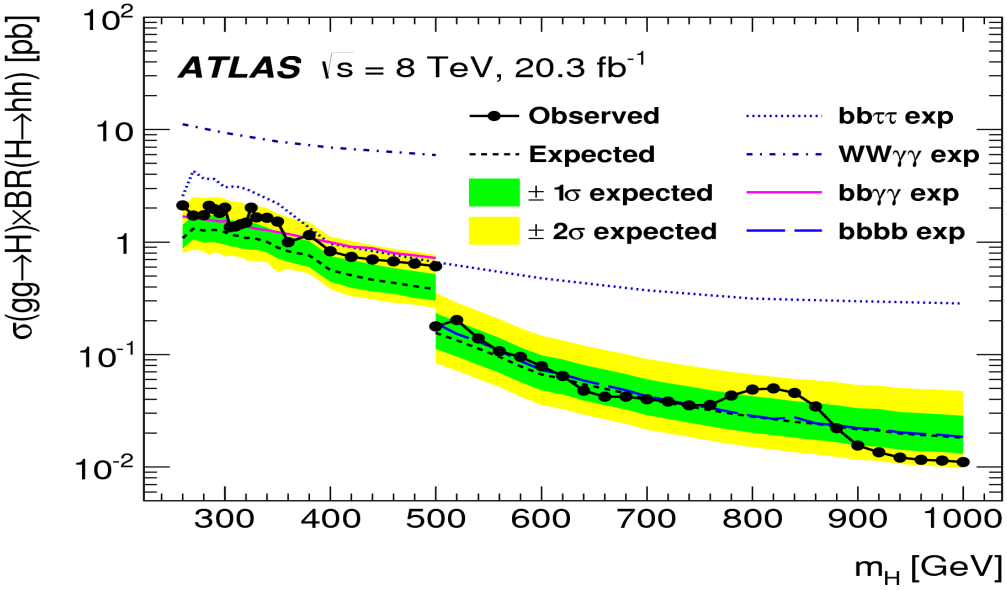
> H±→tb, ATLAS 8 TeV [1512.03704]




Broad excess (up to 2.4σ) more compatible with systematic mismodelling than hypothesized signal

# Some moderate excesses in Run 1 (III)

> resonance → hh, ATLAS 8 TeV [1509.04670]

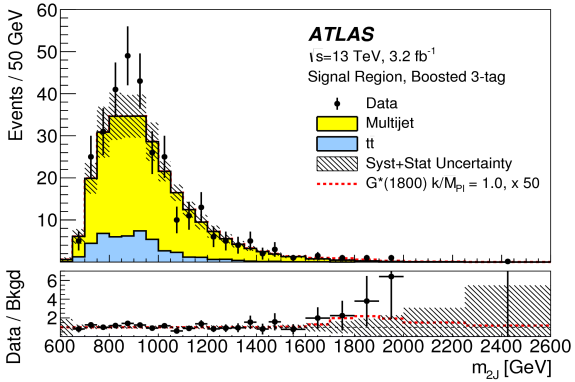



2.5σ local at 300 GeV, largely due to excess in γγbb channel

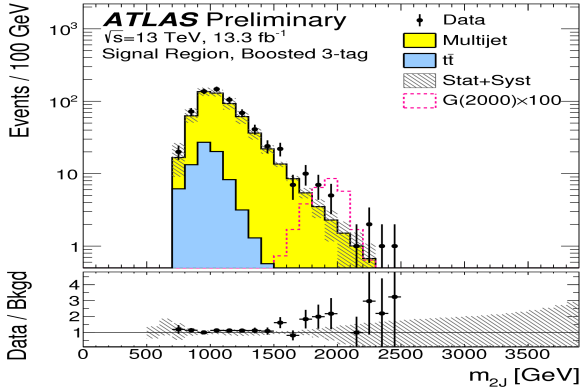
# Some moderate excesses in Run 2

> resonance → hh → bbbb, ATLAS 13 TeV (2015) [1606.04782]

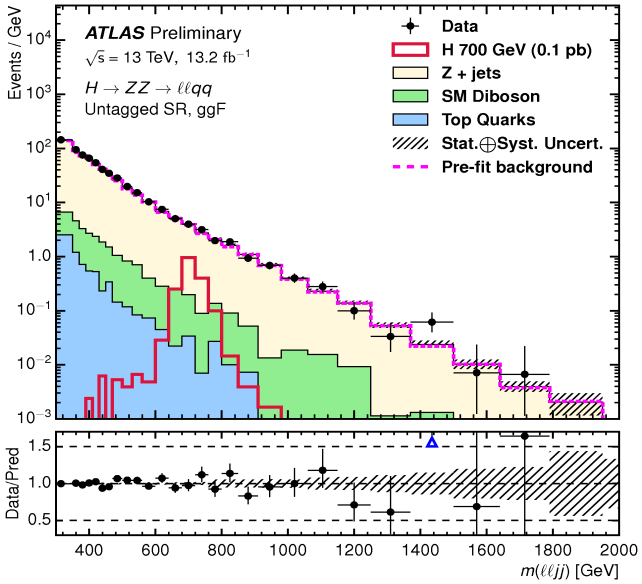
2.0σ local at 900 GeV

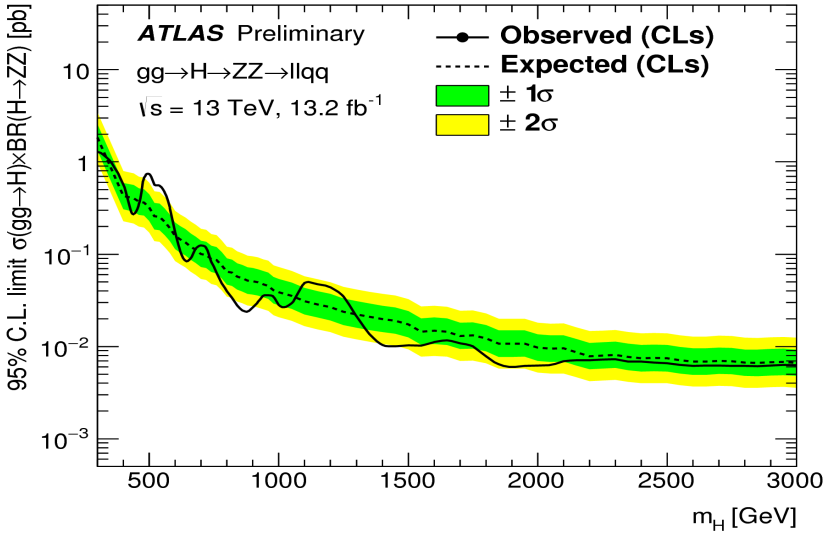



**But excess gone in 2015+2016 data analysis CONF-2016-049**




> resonance → ZZ/WZ → llqq, ATLAS 13 TeV (2015+2016) [ATLAS-CONF-2016-082]




2.75σ local (1.4σ global) at 500 GeV