Searches for rare and beyond Standard Model Higgs boson decay modes and fermion decays of heavy Higgs bosons

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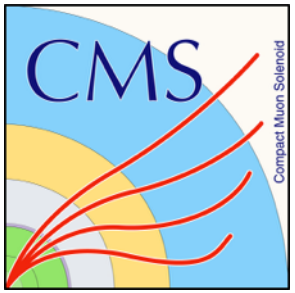
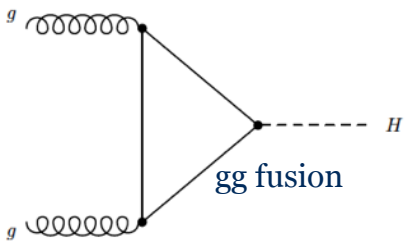
on behalf of CMS and ATLAS Collaborations



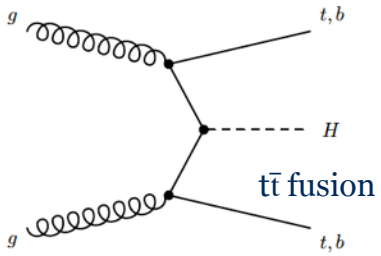
Outline

- 125 GeV Higgs boson
  - SM Higgs rare decay
    - $H \to \mu\mu, ee$
    - $H \to Z/\gamma^* \gamma$
    - $H \to J/\psi\gamma, \Upsilon\gamma, \Phi\gamma$
  - BSM decays:
    - Lepton flavour violating decays
    - H→ invisible
    - H→ aa
- Heavy Higgs boson fermion decays
  - $H \to t\bar{t}$
  - $H^{\pm} \to tb$
  - $H \to bb$
  - $H^{\pm} \to \tau\nu$
  - $H \to \tau\tau$

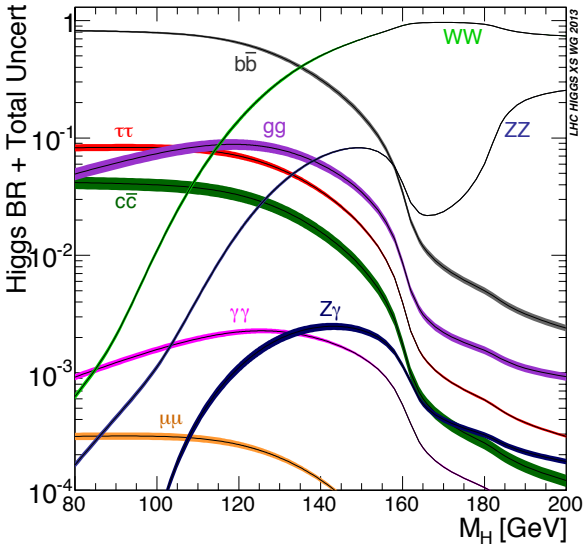
Higgs production and decay



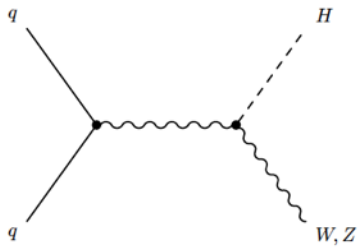
gg fusion



$t\bar{t}$ fusion

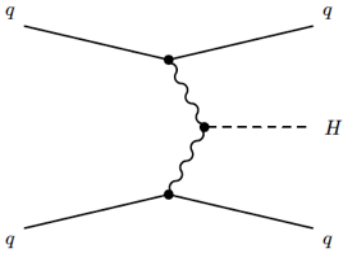


CMS and ATLAS combination using 7 and 8 TeV data
DOI: 10.1007/JHEP08(2016)045



W, Z bremsstrahlung

$$m_H = 125.09 \pm 0.21(stat.) \pm 0.11(syst.)\text{GeV}$$



WW, ZZ fusion

Rare decays:
H→μμ, ee
H→Z/γ* γ
H→J/ψγ, Υγ
H→Φγ

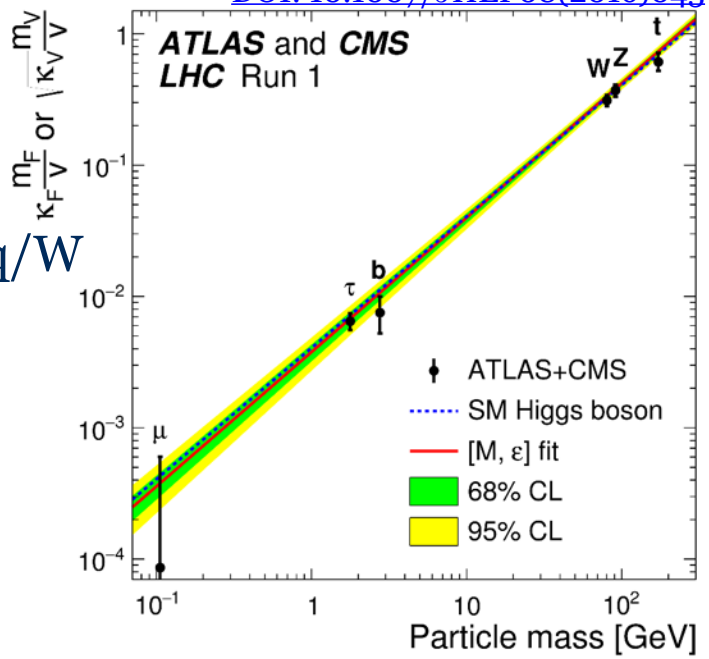
Decay mode	Branching fraction [%]
$H \to bb$	57.5 ± 1.9
$H \to WW$	21.6 ± 0.9
$H \to gg$	8.56 ± 0.86
$H \to \tau\tau$	6.30 ± 0.36
$H \to cc$	2.90 ± 0.35
$H \to ZZ$	2.67 ± 0.11
$H \to \gamma\gamma$	0.228 ± 0.011
$H \to Z\gamma$	0.155 ± 0.014
$H \to \mu\mu$	0.022 ± 0.001

JHEP 08 (2016) 045

Why Higgs rare decay?

- Fully explore Higgs boson
  - Higgs production:
    - Cross section
    - production modes: gg, VBF, V/ttH, tHq/W
  - Higgs decays:
    - Mass
    - Couplings
    - Width
    - Spin/CP
  - Higgs rare decays: New Physics!
    - Poorly constrained
    - Coupling < $O(10^{-3})$
    - Big impact on existing couplings
    - Current limit @ 95% CL: $B(H \to BSM) < 0.34$

DOI: 10.1007/JHEP08(2016)045



- **Consistent with SM, room for BSM**
- Rare decay not observed yet
  - Sensitive to BSM:
    - Yukawa couplings

SM H→μμ

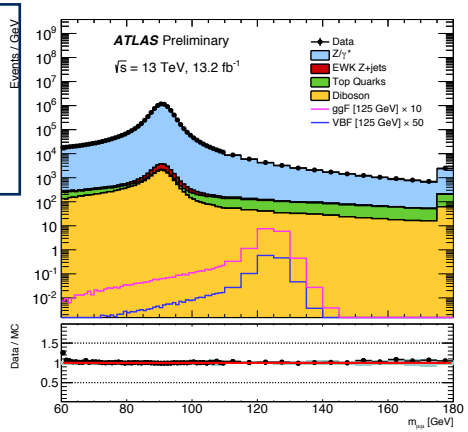
13 TeV

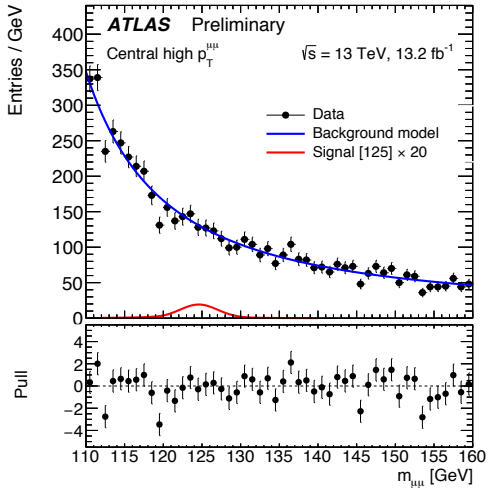
ATLAS EXPERIMENT

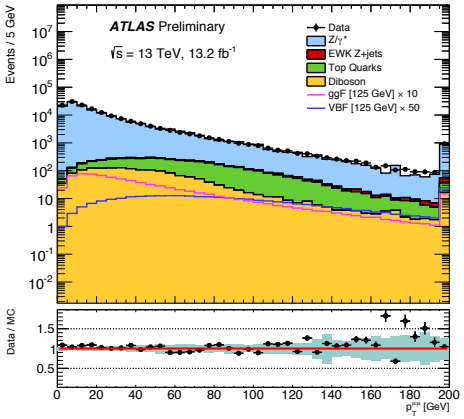
ATLAS-CONF_2016_041

- The most recent result is from ATLAS experiment
- Small but clear signal
- Signal modeling
  - VBF categorised by MVA classifier
  - ggF categorised (6) by $p_T(H)$ and $|\eta_\mu|$
  - Shape parametrised by a Crystal-Ball + Gaussian
- Dominated by $Z/\gamma^* \rightarrow \mu\mu$ (continuum) background
- Shape and normalisation derived by fitting to the di-muon mass spectra: Breit-Wigner ⊗ Gaussian(Z-peak)+e^{Ax}/x^3 (continuum)

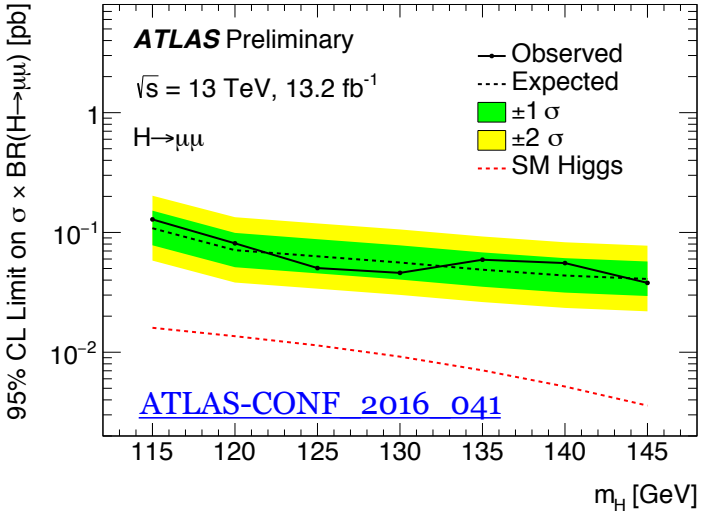
measurement of muon Higgs Yukawa coupling







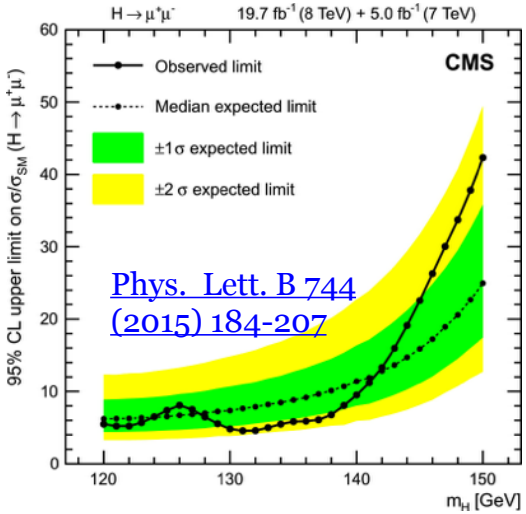
SM H→μμ, H→ee



H→μμ cross section limit / SM (signal strength)

- ATLAS Run2, m_H= 125.09 GeV
  - μ < 4.4 (obs.), < 5.5 (exp.)
- ATLAS Run1+Run2, m_H= 125.09 GeV
  - μ < 3.5 (obs.), < 4.3 (exp.)

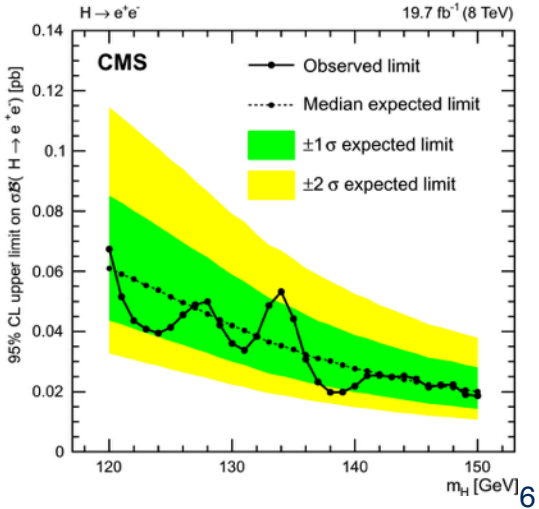
- CMS Run1:
  - m_H= 125 GeV, 95% CL upper limits: < 7.4 (6.5) obs (exp)
    - B(H→μμ) < 0.0016 assuming σ_{SM}
  - 0.8σ global significance



CMS H→ee obs limits:

- σ(H)xB<0.041 pb
- B<0.0019 (~3.7 x 10^5 SM B)

- CMS Run1: H→ee
  - Extremely rare



SM $H \rightarrow Z/\gamma^{*}\,\gamma$

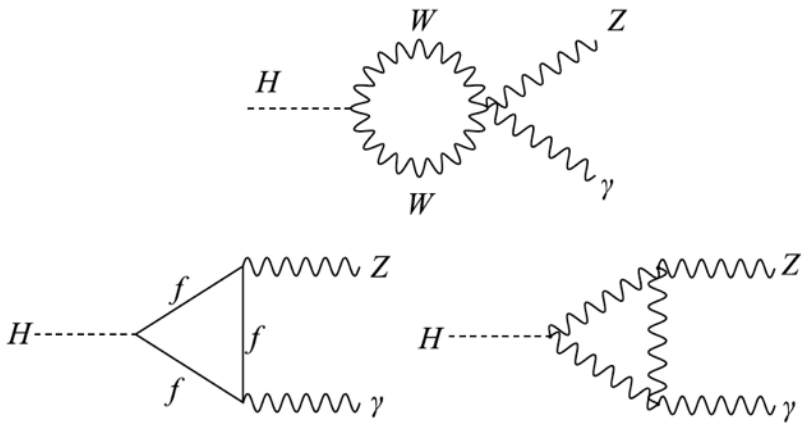
7, 8 TeV

ATLAS EXPERIMENT

CMS

- 2 lepton and 1 photon in the final state: relatively clean events!
- Small expected yield: categorisation to enhance the sensitivity

  - ATLAS Zγ Phys. Lett. B 732C(2014), 8-27:
    - $m_{ll} > m_Z$ - 10 GeV, $115 < m_{ll\gamma} < 170$ GeV
    - categorisation (10 cat.): pp centre-of-mass energy (7 or 8 TeV), lepton flavour, $\Delta\eta_{Z\gamma}$, p_{Tt}^{*} (> or < 30 GeV)



  - CMS Phys. Lett. B 726(2013) 587-609:
    - $m_{ll} > 50$ GeV, $100 < m_{ll\gamma} < 190$ GeV
    - $m_{\gamma\gamma} + m_{ll} > 185$ GeV
    - 10 categories: lepton flavour, lepton η, photon η, shower shape R_9

* higgs boson p_T component orthogonal to the Zγ thrust axis in the transverse plane

SM H→Zγ

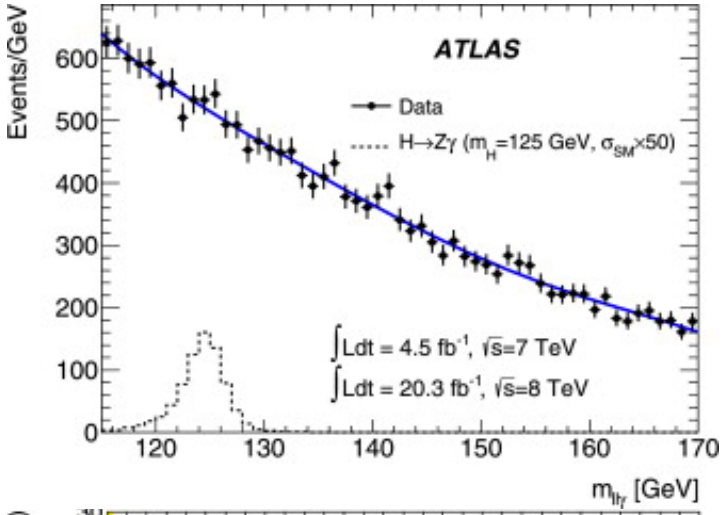
7, 8 TeV

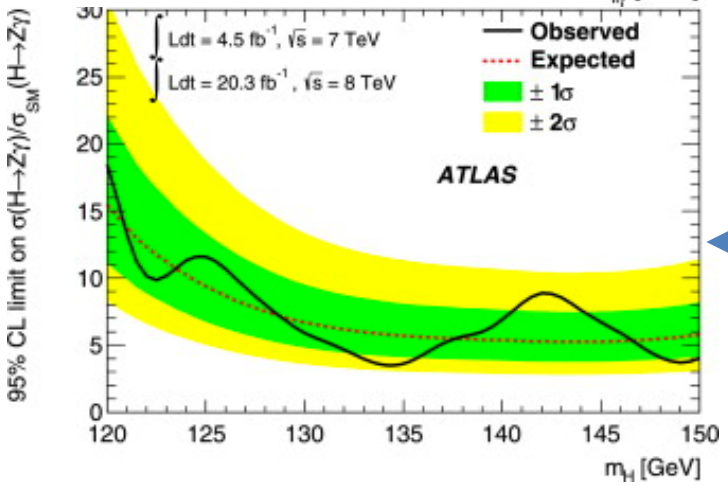
ATLAS EXPERIMENT

CMS

[Phys. Lett. B 732C(2014), 8-27]

[Phys. Lett. B 726(2013) 587-609]





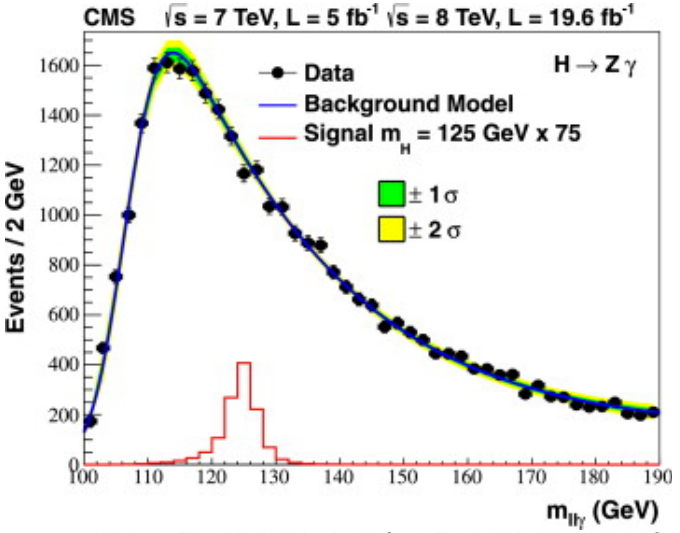
No significant excess over background predictions has been observed by both experiments

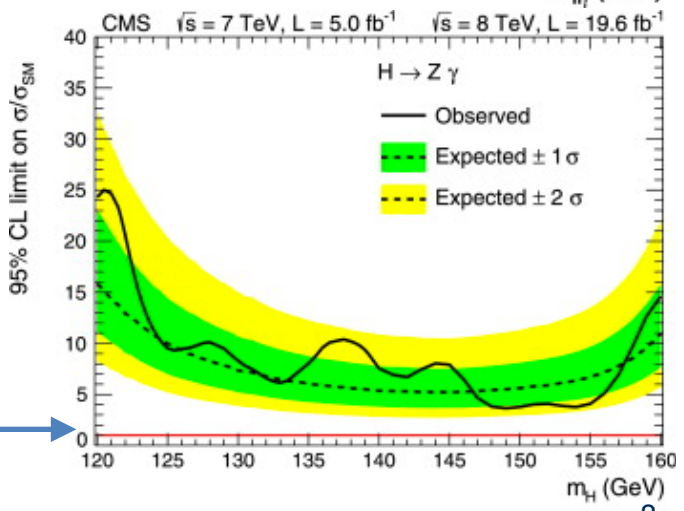
ATLAS:

- μ< 11 (obs), 9 (exp) @ 95% CL for m_H = 125.5 GeV

CMS limits (125GeV):

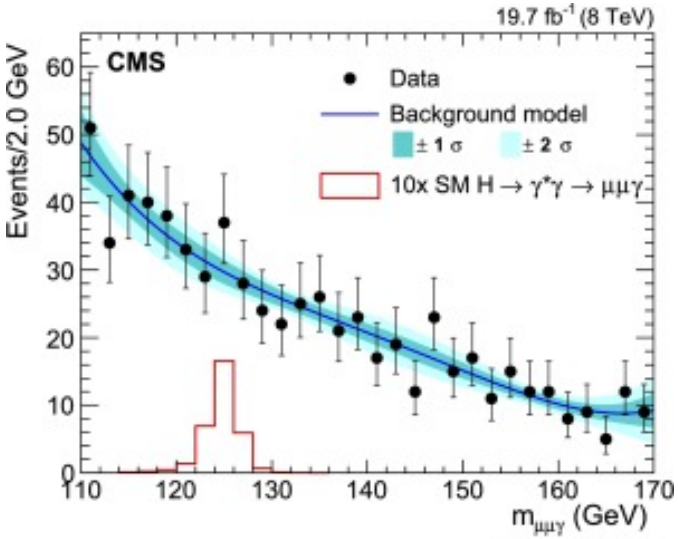
- σ/σ_{SM} < 9.5 (obs), 10 (exp)

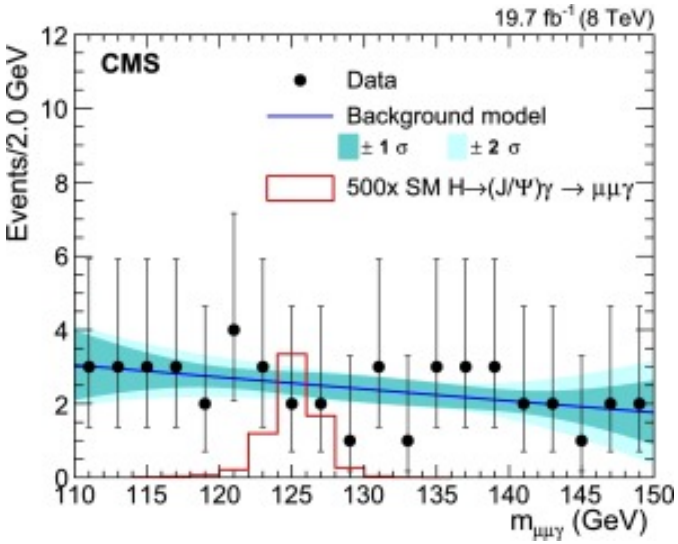




SM H→γ*γ

8 TeV

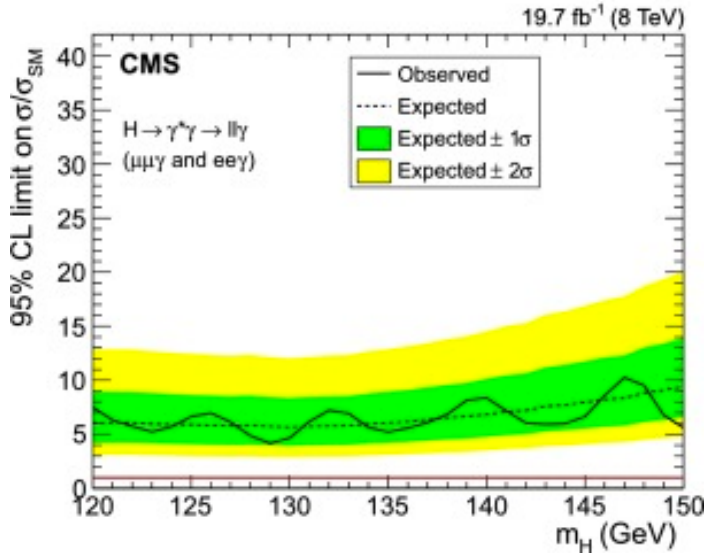




CMS performed the search using low di-lepton mass
- very similar to the H→Zγ analysis
- $m_{ll} < 20$ GeV

No significant excess above SM prediction:
- $\sigma/\sigma_{SM}(125\ \text{GeV}) < 6.7$ (obs), 5.9 (exp)

Phys. Lett. B 753 (2016) 341



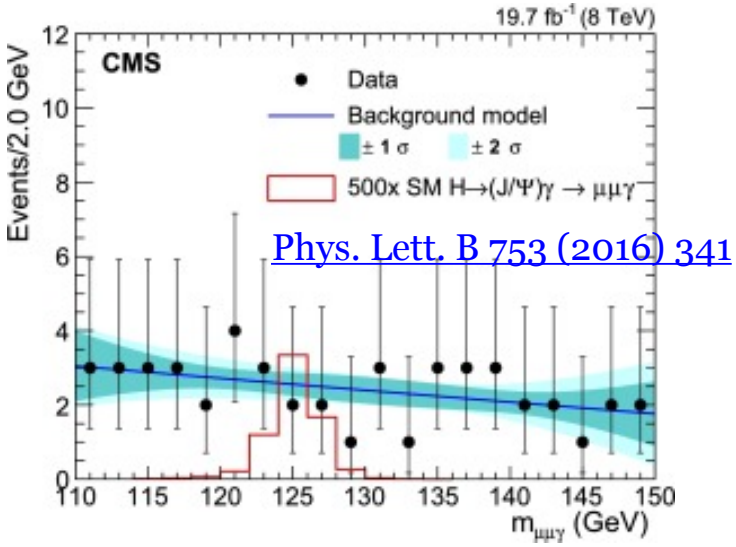
H→J/ψγ

8 TeV

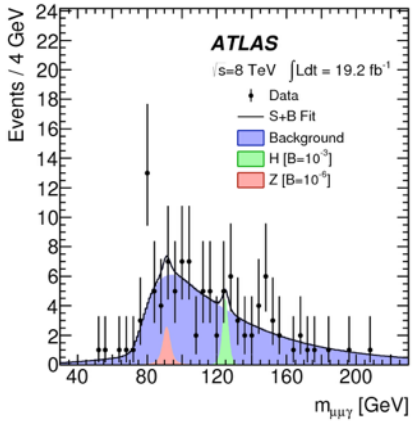
Explore H→cc̄ coupling

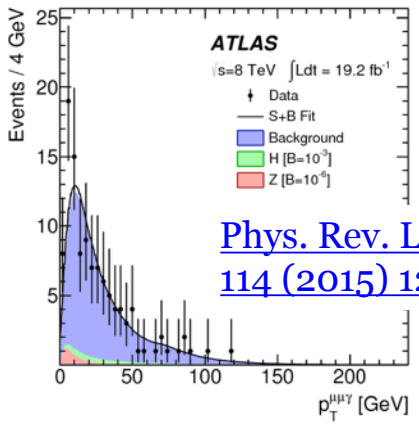
CMS performed the search requiring $2.9 < m_{\mu\mu} < 3.3$ GeV

- very similar to the H→γ*γ analysis
- $\sigma(pp\to H)B(H\to J/\psi\gamma) < 1.80$ fb (obs), 1.90 (exp)
- $B(H\to J/\psi\gamma) < 1.5\times10^{-3}$, 540 times theoretical prediction[1]



Phys. Lett. B 753 (2016) 341





Phys. Rev. Lett. 114 (2015) 121801

ATLAS:

- inclusive QCD background modelled by data-driven template fitting
- 2 muons and 1 photon $\Delta\Phi(\mu\mu,\gamma) > 0.5$
- 4 categories: η_μ and photon reconstruction classification
- $|\, m(\mu\mu) - m(J/\psi) \,| < 0.2$ GeV
- Simultaneous unbinned maximum likelihood fit on $m_{\mu\mu\gamma}$ and $p_{T\mu\mu\gamma}$
- $B(H\to J/\psi\gamma) < 1.5 \times 10^{-3}$

[1] G.T. Godwin et al. http://dx.doi.org/10.1103/PhysRevD.90.113010

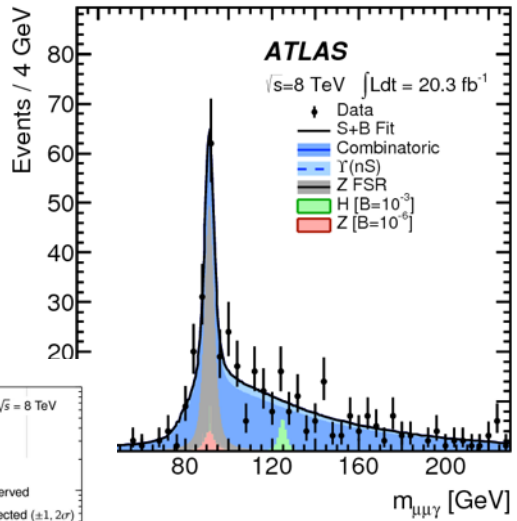
H→Υ(nS)γ and H→Φγ

8, 13 TeV

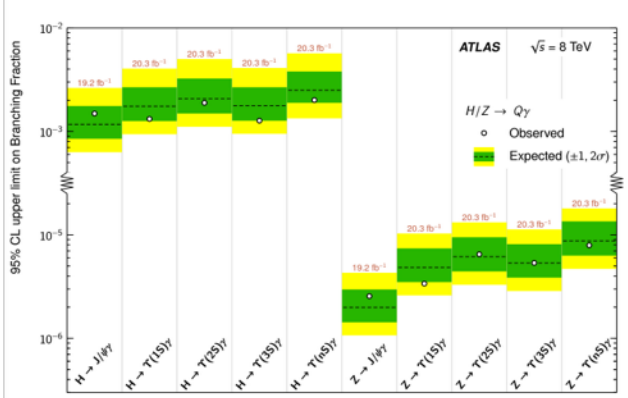
ATLAS EXPERIMENT

H→Υ(nS)γ: Explore H→bb̄ coupling

- Simultaneous unbinned maximum likelihood fit on $m_{\mu\mu\gamma}$, $p_T^{\mu\mu\gamma}$, $m_{\gamma\gamma}$
- $B(H\to\Upsilon(nS)\gamma) < 1 - 2\ 10^{-3}$
- Limit ~ 10^7 SM



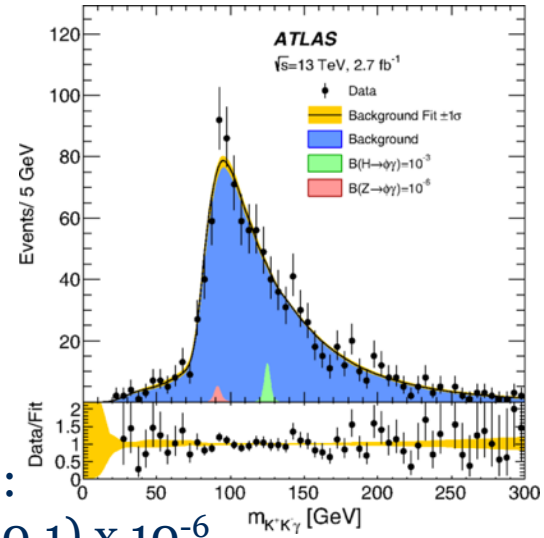
Phys. Rev. Lett. 114 (2015) 121801



H→Φγ : Explore H→ss̄ coupling

- reconstructed: Φ→K⁺K⁻
- inclusive QCD and γ+jets background by data driven method
- unbinned maximum likelihood fit to $m_{K^+K^-\gamma}$

Phys. Rev. Lett. 117, 111802



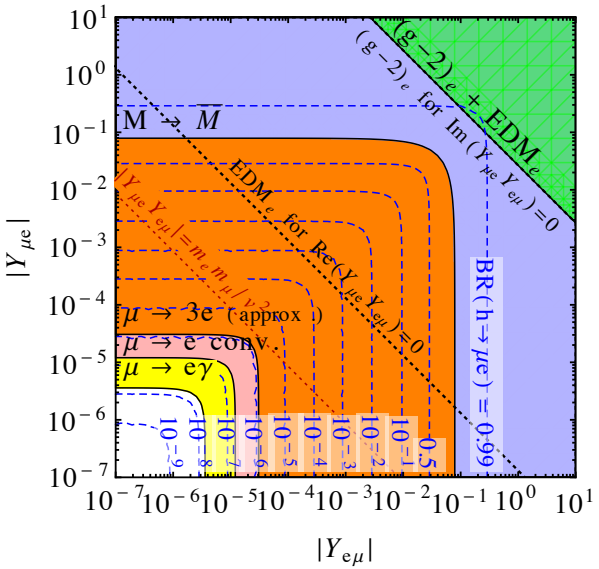
- expected from SM: $B(H\to\Phi\gamma) = (2.3\pm0.1) \times 10^{-6}$
- $B(H\to\Phi\gamma)<1.4\times10^{-3}$ @ 95%CL

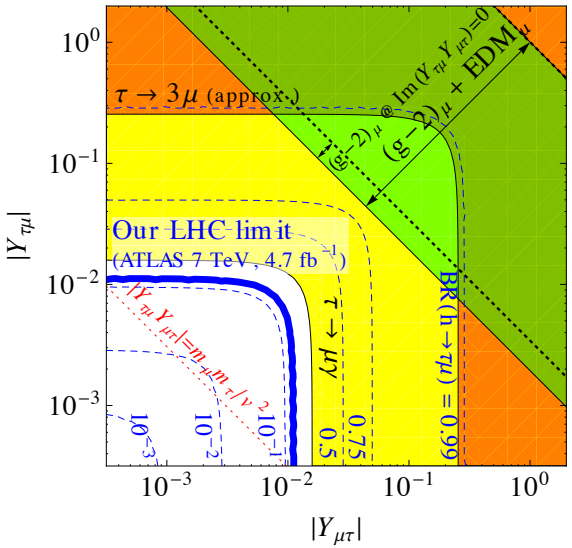
LFV Higgs decays

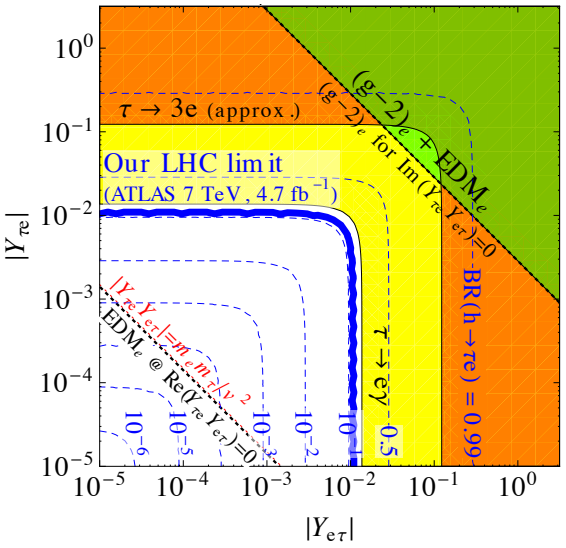
- The flavour sector can be a probe to investigate new physics.
- BSM models (double Higgs models or extra dimensions) allow LFV decay of the boson.
- No direct limits before LHC analyses:
  - indirect limits allow room to see BSM coupling with ATLAS and CMS searches
  - R. Harking et al, doi:10.1007/JHEP03(2013)026 reinterpreted ATLAS H→ττ search at 8 TeV: B(H→μτ/eτ) < O(10%)

$$Y = \begin{pmatrix} \boxed{Y_{ee}} & Y_{e\mu} & Y_{e\tau} \\ Y_{\mu e} & \boxed{Y_{\mu\mu}} & Y_{\mu\tau} \\ Y_{\tau e} & Y_{\tau\mu} & \boxed{Y_{\tau\tau}} \end{pmatrix}$$

SM values







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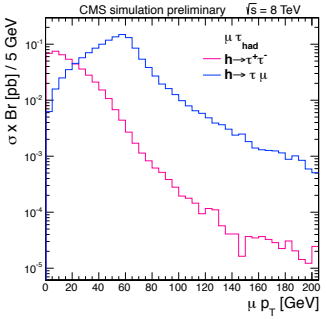
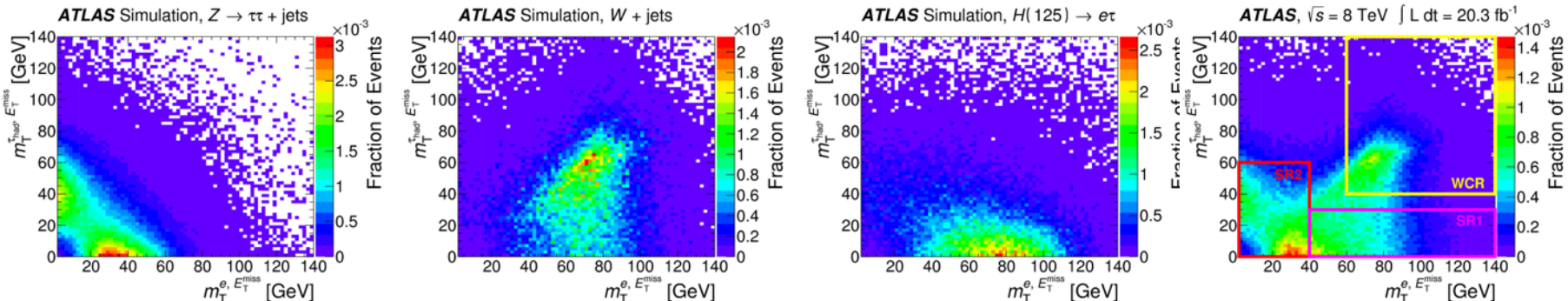
LFV Higgs decays

8, 13 TeV

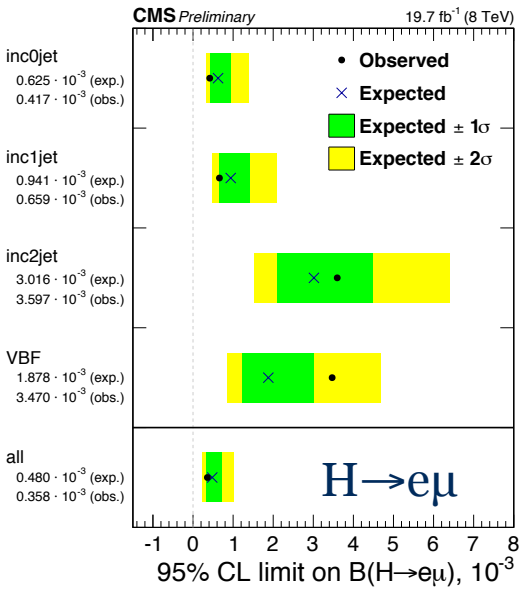
- Similar strategy for H→e-τ, H→μ-τ channels
- CMS: Phys. Lett. B 749 (2015) 337, arXiv:1607.03561
  - 2 channels (τ_l, τ_h), 3 categories (0, 1, 2 jets)
  - log-likelihood fit to the l-τ collinear mass distribution
  - H→eμ investigated as well. Targeting a very small B. | 10 categories, fit to the invariant mass distribution
- ATLAS: JHEP 1511 (2015) 211, arXiv:1604.07730
  - l-τ_h, 2 categories (M_T), fit to the MMC (missing mass calculation) distribution
  - l-τ_l, 2 categories (no jets, jets), fit to the collinear mass distribution
- full statistics of 8 TeV dataset: 19.7 fb^{-1} (CMS), 20.3 fb^{-1} (ATLAS)
  - CMS updated the search using 2015 dataset (2.3 fb^{-1}): CMS-PAS-HIG-16-005

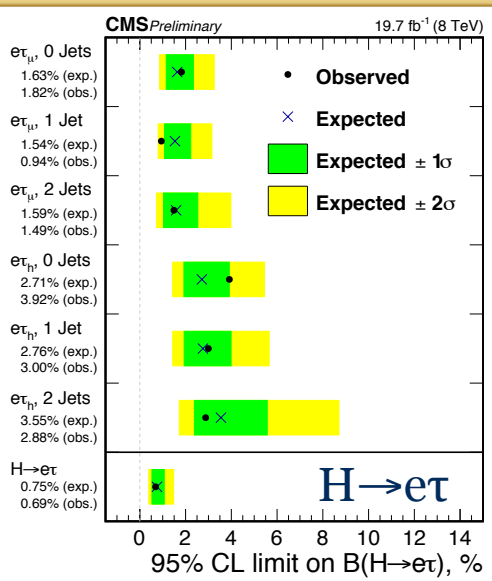


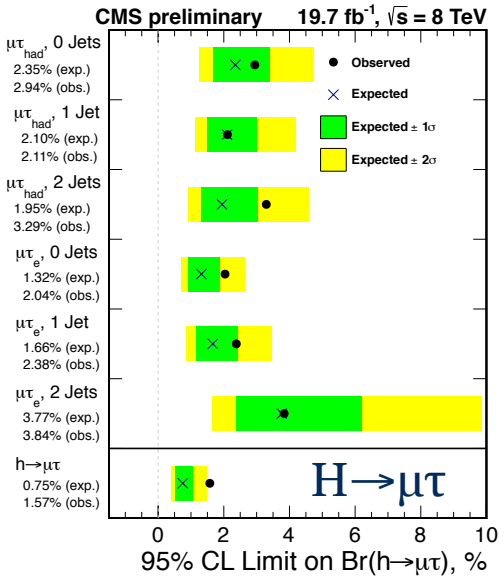


LFV decays: CMS limits

8, 13 TeV

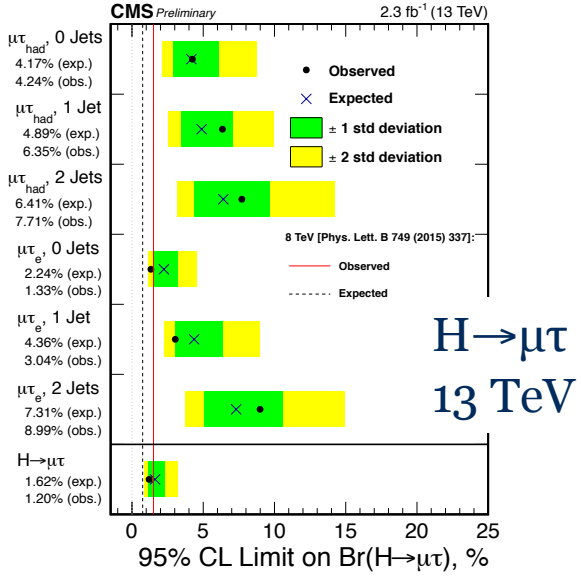






- B(H→eμ) < 0.036% (obs), 0.048% (exp)
- B(H→eτ) < 0.69 % (obs), 0.70% (exp)
- B(H→μτ) < 1.52 % (obs), 0.75% (exp)
  - small deviation per categories

- 13 TeV: B(H→μτ) < 1.20 % (obs), 1.65% (exp)
  - no excess, but not sensitive enough to exclude 8 TeV result

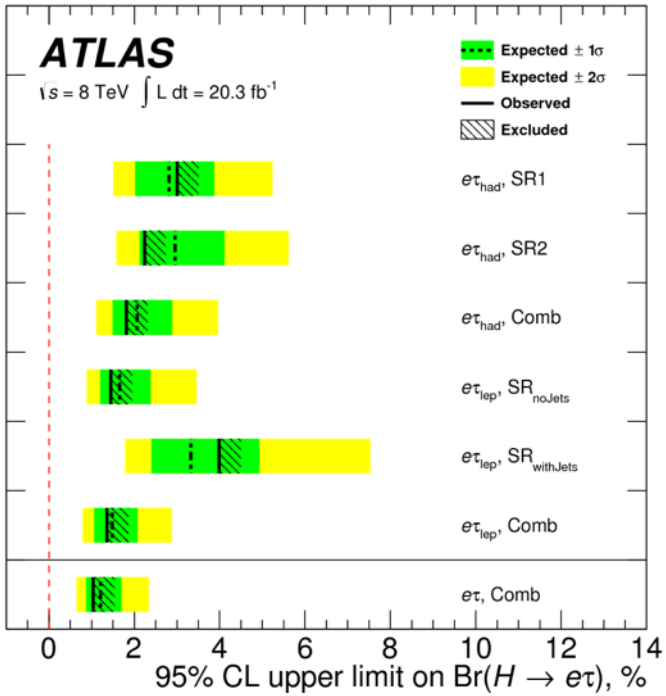


LFV decays: ATLAS limits

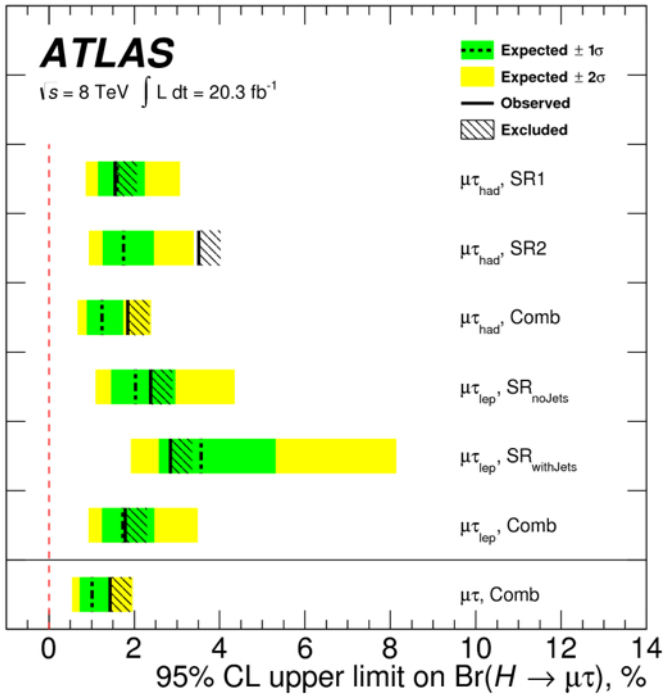
ATLAS EXPERIMENT

8 TeV

H→eτ



H→μτ



- B(H→eτ) < 1.04 % (obs), 1.21% (exp)
- B(H→μτ) < 1.43 % (obs), 1.01% (exp)
  - small 1σ excess driven by H→μτ$_h$

LFV decays: results

ATLAS EXPERIMENT

CMS

Branching ratios:

Channel	Experiment	95% CL obs (exp) limits	Best Fit
$H\to \mu e$	CMS 8 TeV	0.036% (0.048%)	-
$H\to e\tau$	ATLAS 8 TeV	1.04% (1.21%)	-
$H\to e\tau$	CMS 8 TeV	0.69% (0.75%)	-
$H\to \mu\tau$	ATLAS 8 TeV	1.43% (1.01%)	$0.53^{+0.51}_{-0.51}\%$
$H\to \mu\tau$	CMS 8 TeV	1.51% (0.75%)	$0.84^{+0.39}_{-0.37}\%$
$H\to \mu\tau$	CMS 13 TeV	1.20% (1.62%)	$0.76^{+0.81}_{-0.84}\%$

95% CL limits on Higgs Yukawa coupling

Channel	Coupling	pre-LHC	CMS	Atlas
$H\to \mu e$	$\sqrt{\lvert Y_{\mu e}\rvert^2 + \lvert Y_{e\mu}\rvert^2}$	$3.6\cdot 10^{-6}$	$5.4\cdot 10^{-4}$	-
$H\to \mu\tau$	$\sqrt{\lvert Y_{\mu\tau}\rvert^2 + \lvert Y_{\tau\mu}\rvert^2}$	0.016	0.0036	0.0035
$H\to e\tau$	$\sqrt{\lvert Y_{e\tau}\rvert^2 + \lvert Y_{\tau e}\rvert^2}$	0.014	0.0024	0.0029

limits improved by 1 order of magnitude

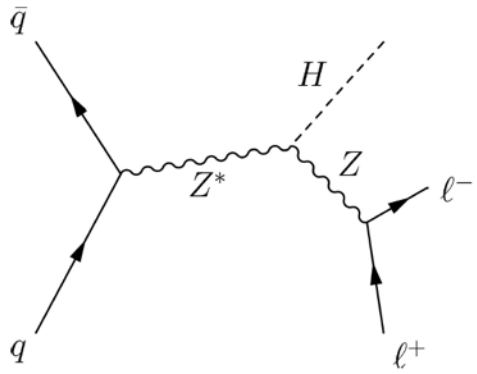
H→invisible: ZH

13 TeV

ATLAS EXPERIMENT

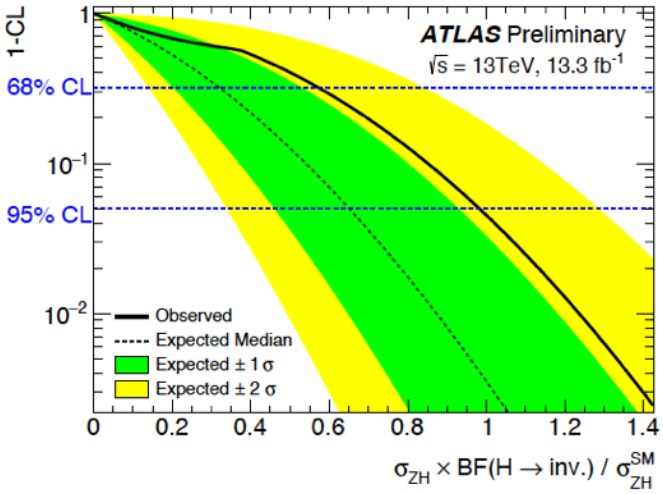
CMS

- SM rare process $B(H \to Z^{*}Z \to 4\nu) < 0.1\ \%$
- It can have many contribution from BSM models

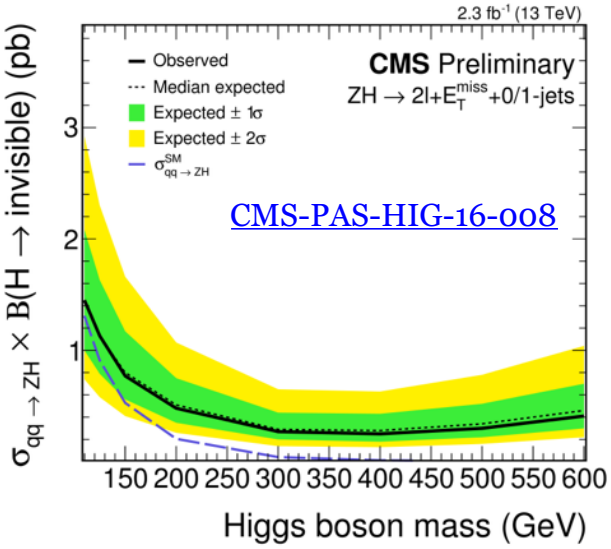


- searches performed using ZH:
  - low production cross-section
  - low background
- 2 leptons having $m_{ll} = m_Z$
- CMS: 2.3 fb^{-1} at 13 TeV
  - no significant excess observed
  - $\sigma(ZH)B(H \to inv.) < 1.1\ (1.1)$ pb obs. (exp.)
- ATLAS: 13.3 fb^{-1} at 13 TeV
  - no significant excess observed
  - $B(H \to inv.) < 0.98$ (obs), 0.65 (exp.)

ATLAS-CONF-2016-056



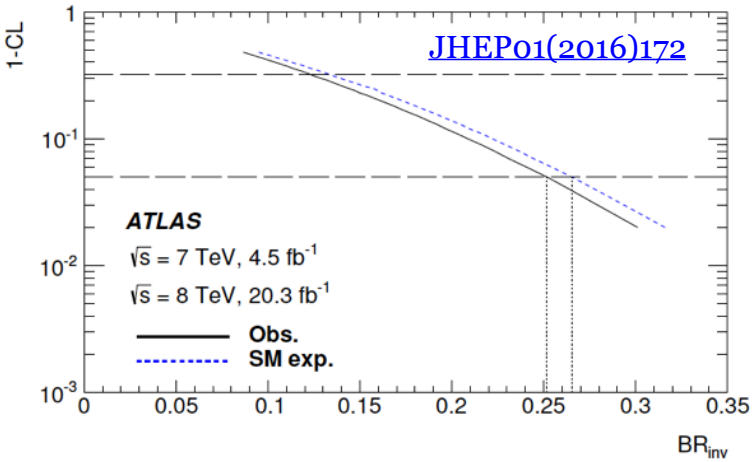
CMS-PAS-HIG-16-008

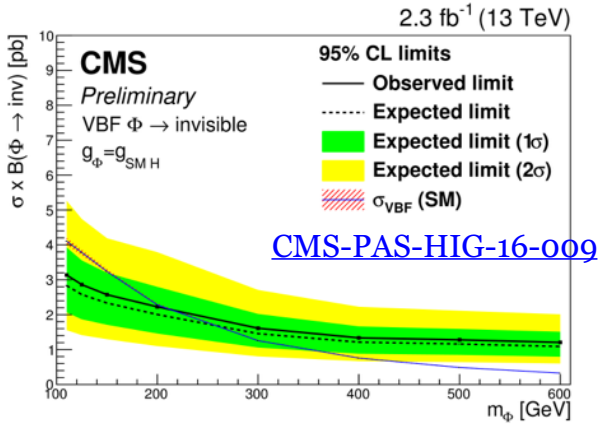


H→invisible: VBF H

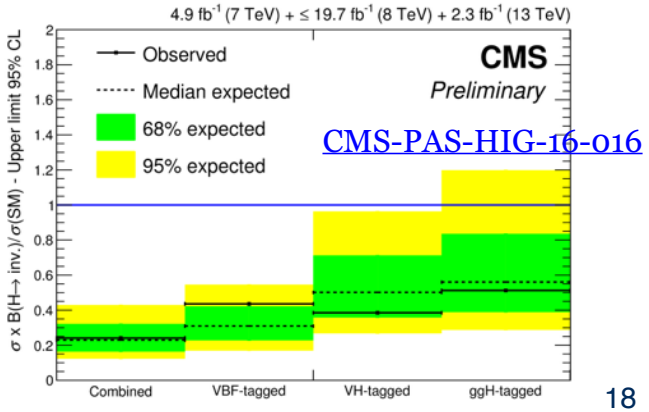
7, 8, and 13TeV

- Larger cross section than ZH and larger background (Z→νν, W+jets, QCD)
- VBF: 2 jets with large $\Delta\eta_{jj}$ and m_{jj}
- CMS: 2.3 fb^{-1} at 13 TeV
  - no excess observed
  - B(H→inv) < 0.69 (obs), 0.62 (exp)
  - Combination with ZH and 8 TeV analysis:
    - B(H→inv) < 0.32 (obs), 0.26 (exp)
- ATLAS: 20.3 fb^{-1} at 8 TeV
  - no excess observed
  - B(H→inv) < 0.28 (obs), 0.31 (exp)
  - Combination with other production channels:
    - B(H→inv) < 0.25 (obs), 0.27 (exp)





- CMS combination qqH+ISR and VH (RunI and RunII):
  - B<0.24 (0.23) obs (exp)

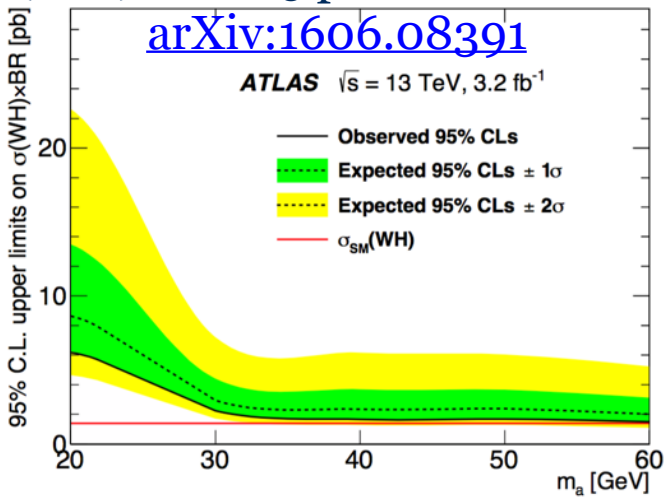


H→aa

8, 13 TeV

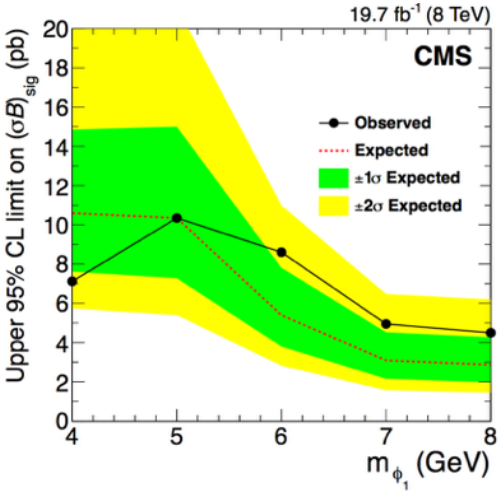
- ATLAS performed the search using 3.2 fb^{-1} of data at 13 TeV:
- H→aa→bbbb
- m_a=20-60 GeV
- production channel WH:
  - 1 lepton from W, MET, b-jets
  - 8 categories (3SR, 5 CR): # jets, # b-jets

Upper limit:
σ(WH)xB < 6.2 pb m_a = 20 GeV
σ(WH)xB < 1.5 pb for m_a = 60 GeV



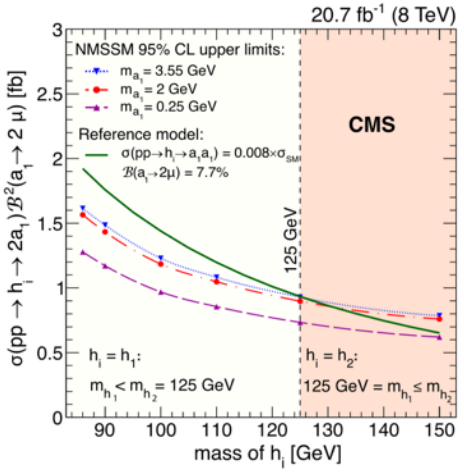
arXiv:1606.08391

- CMS looked for lighter bosons using 8 TeV data. Most recent results:
  - H→aa→ττττ
  - H→aa→μμμμ



H→aa→ττττ
JHEP 01 (2016) 079

H→aa→μμμμ
Phys. Lett. B 752 (2016), 146-168



Heavy Higgs Boson

- Observed 125 GeV Higgs boson is very consistent with the SM
- Search for a heavier Higgs-like particle
- Most used in the model dependent searches:
  - 2-Higgs-Doublet Model (2HDM)
    - physical particles: h, H, A, $H^{\pm}$
    - parameters:
      - masses: m_h, M_H, m_A, $M_{H\pm}$
      - VEV ratio of the two doublets: tanβ
      - Mixing angle between h, H: α
      - potential mixing of the two doublets: m_{12}^2
    - Different way of doublet - particle coupling:

in 2HDM, h or H (CP-even, neutral) could be the 125 GeV Higgs boson

- Higgs →fermions:
  - $H^+ \to tb$
  - $H^+ \to cb$
  - $H^+ \to \tau\nu$
  - $H \to \tau\tau$

Model	Up-type Quarks	Down-type Quarks	Charged Leptons
Type-I	Φ_2	Φ_2	Φ_2
Type-II	Φ_2	Φ_1	Φ_1
Lepton-specific(Type-X)	Φ_2	Φ_2	Φ_1
Flipped(Type-Y)	Φ_2	Φ_1	Φ_2

MSSM

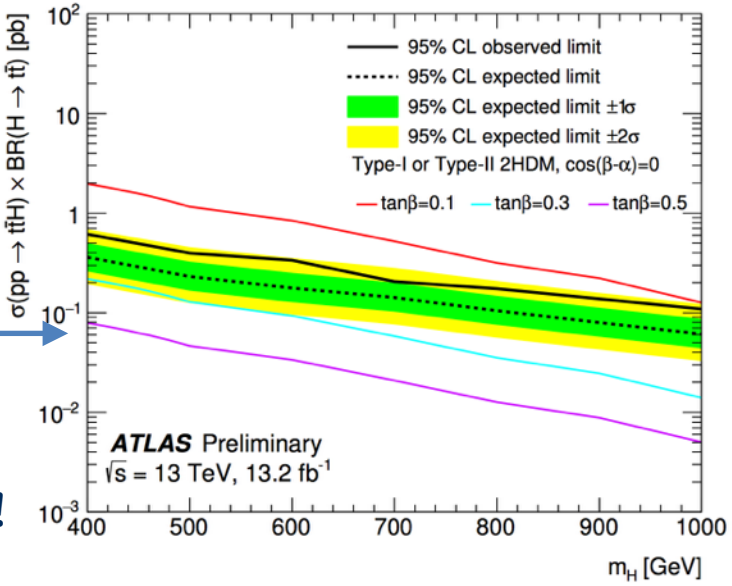
H→tt̄

8, 13TeV

ATLAS EXPERIMENT

- the top quark mass close to EWK symmetry breaking scale
- t-H Yukawa coupling ~ 1
- BSM models predicts large B(H→tt̄)

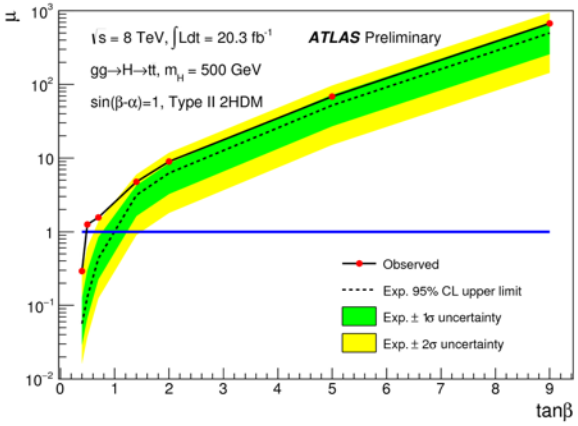
tt/bb H with H→tt at 13 TeV



gg→H→tt search at 8 TeV

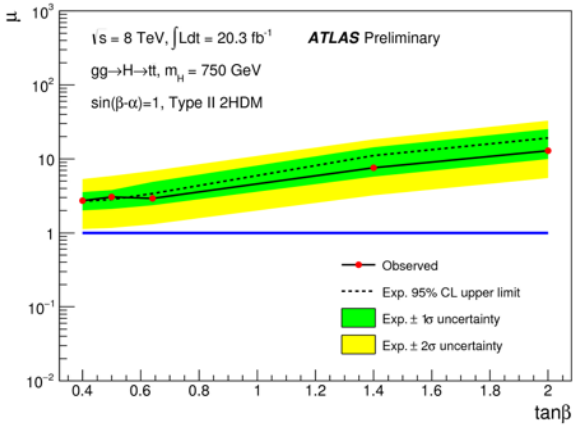
- 2 masses: 500 and 750 GeV

- interference gg→H→tt and tt̄ taken into account!



investigated the pseudo scalar hypothesis too

ATLAS-CONF-2016-073



ATLAS-CONF-2016-104

lower obs (exp) limits

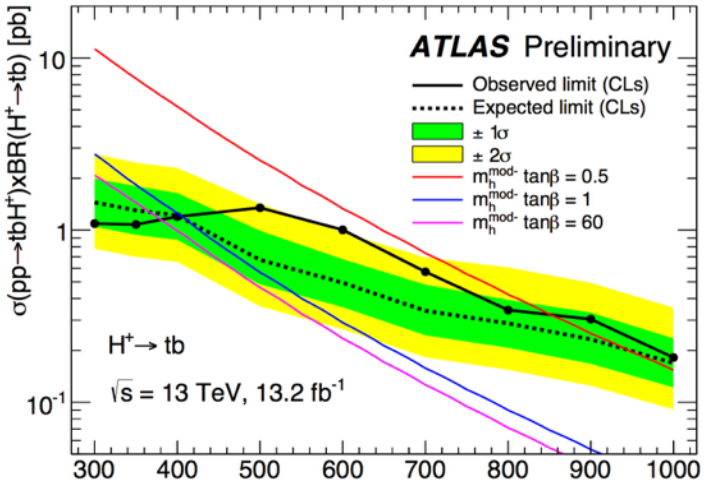
- tan β < 0.17 (0.23) for m_H = 400 GeV
- tan β < 0.11 (0.15) for m_H = 1 TeV

$H^{\pm} \rightarrow tb$

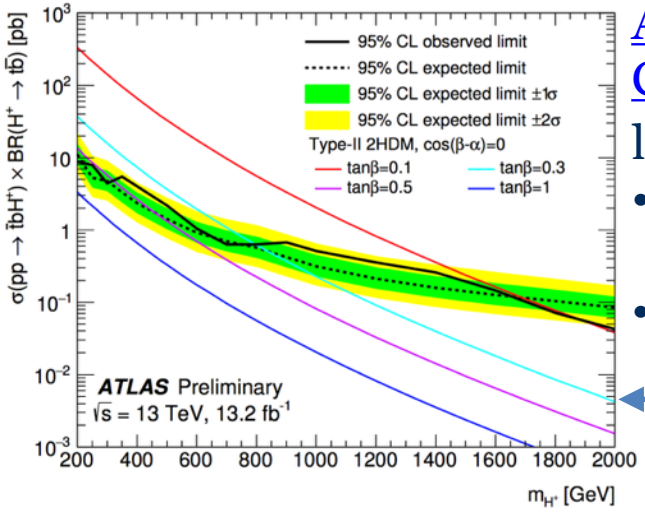
13 TeV

ATLAS EXPERIMENT

- ATLAS explored $gb \rightarrow tH^{\pm}$
  - $H^{\pm} \rightarrow tb$ and (both) $t \rightarrow Wb$
- 13.2 fb^{-1} at 13 TeV
- ≥ 5 jets: 2 from one W and ≥ 3 b-jets
- 1 high p_T lepton (e or μ) from the other W
- 8 categories: # of jet, # of b-jets
- simultaneous binned maximum likelihood fit in the 8 categories (4SR, 4CR)
  - each mass hypothesis tested separately



ATLAS-CONF-2016-089

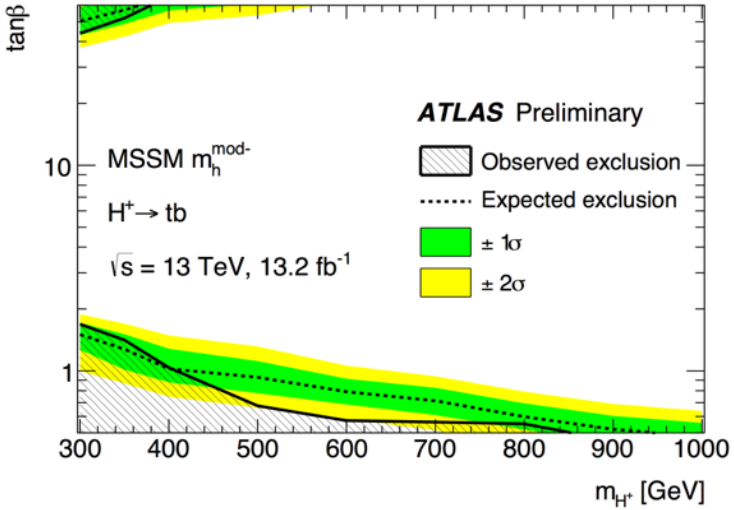


ATLAS-CONF-2016-104

lower obs (exp) limits

- $\tan\beta < 0.65$ (0.55) for $m_H = 200$ GeV
- $\tan\beta < 0.15$ (0.25) for $m_H = 1$ TeV

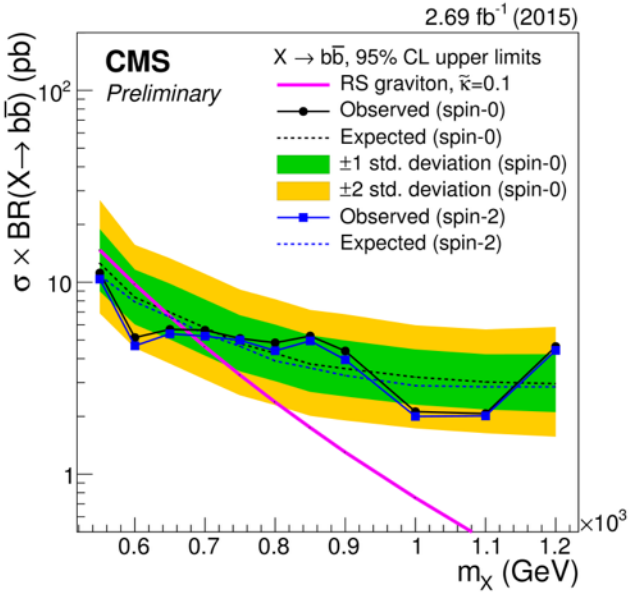
analysis optimised for $H \rightarrow tt$

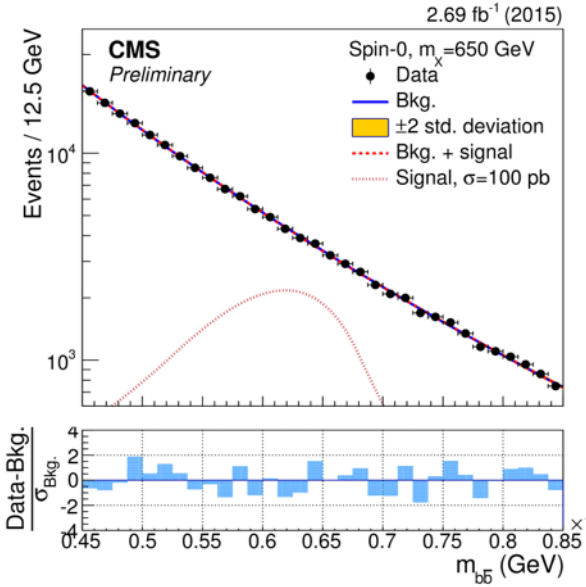


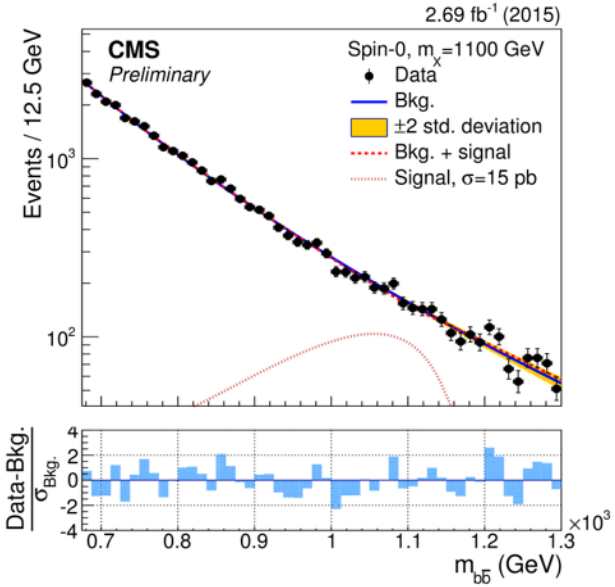
H→bb

13 TeV

- mass range = 550 - 1200 GeV
- 2.69 fb^{-1} at 13 TeV
- 2 energetic b-jets
- veto on pairs of muons or electron
  - inverted to select contro region
- binned max likelihood fit to the $m_{b\bar{b}}$ distribution





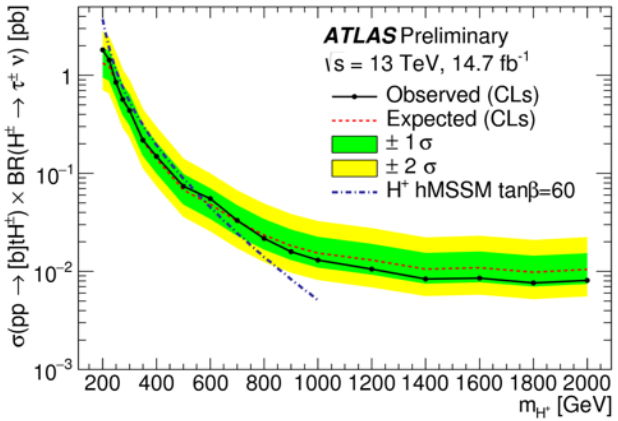


[CMS-PAS-HIG-16-025]

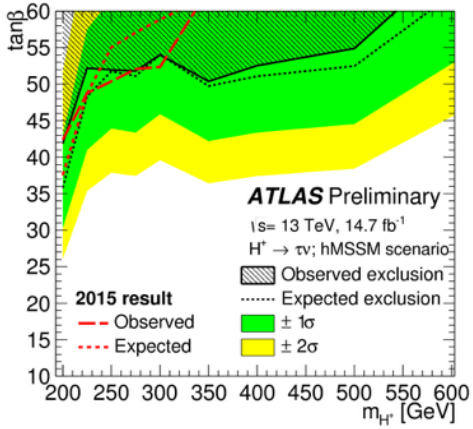
$H^{\pm} \rightarrow \tau\nu$

13 TeV

- $H^{+} \rightarrow \tau\nu$ can be significant for high tanβ
- ATLAS considers $pp \rightarrow tbH^{\pm}$ for masses larger than m_t

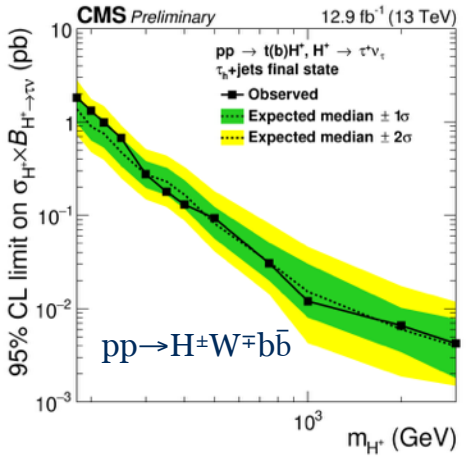


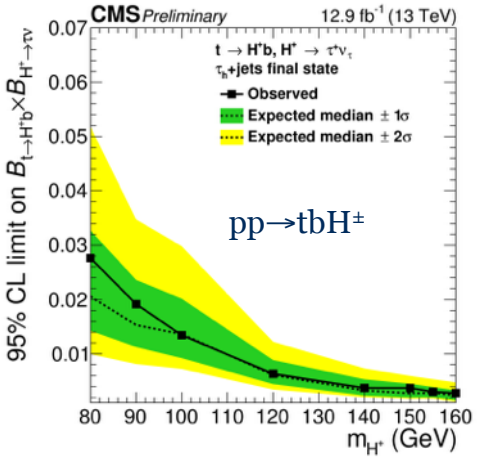
hMSSM scenario



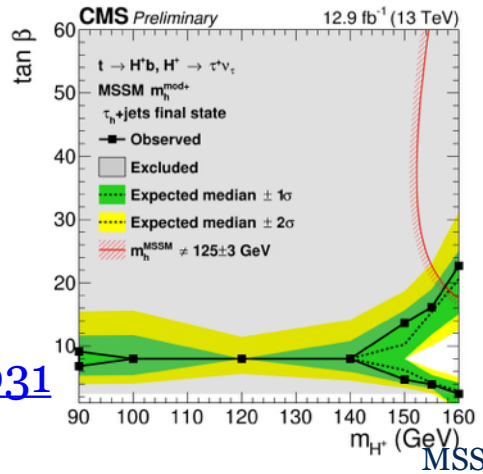
[ATLAS-CONF-2016-088]

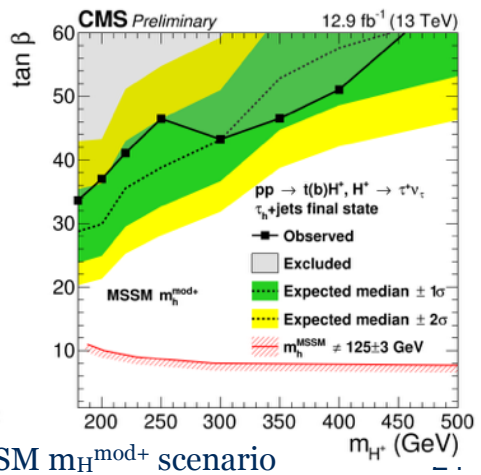
- CMS considers 2 production mode:
  - $pp \rightarrow tbH^{\pm}$ or $pp \rightarrow H^{\pm}W^{\mp}b\bar{b}$ for masses larger or smaller than m_t





[CMS-PAS-16-031]





MSSM m_H^{mod+} scenario

UNIVERSITY OF NOTRE DAME

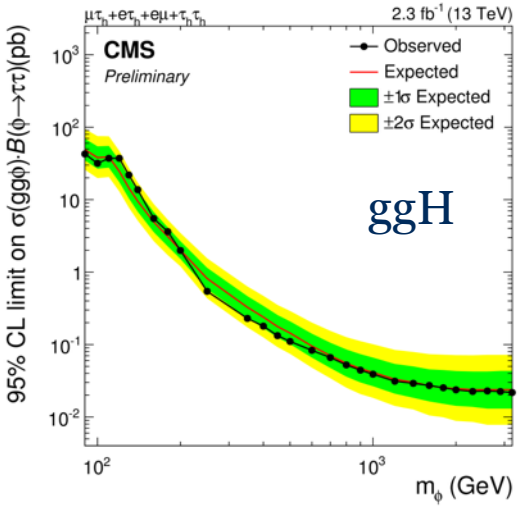
H/A → ττ

13 TeV

ATLAS EXPERIMENT

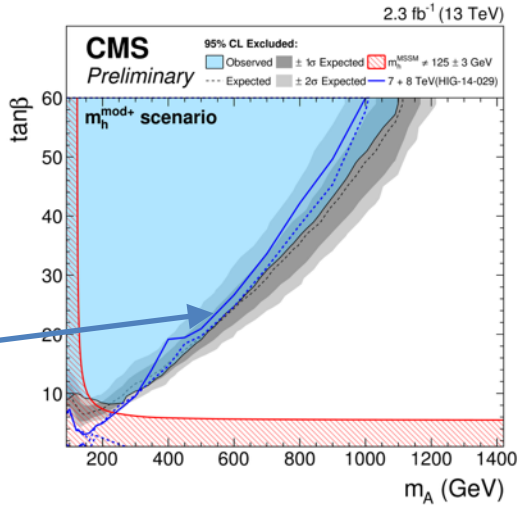
CMS

- CMS: 2.3 fb^{-1} from 2015 data
  - 4 channels: $\tau_e\tau_h$, $\tau_\mu\tau_h$, $\tau_e\tau_\mu$, $\tau_h\tau_h$
  - 2 categories: 0 b-jet, ≥ 1 b-jet
  - CMS-PAS-HIG-16-006



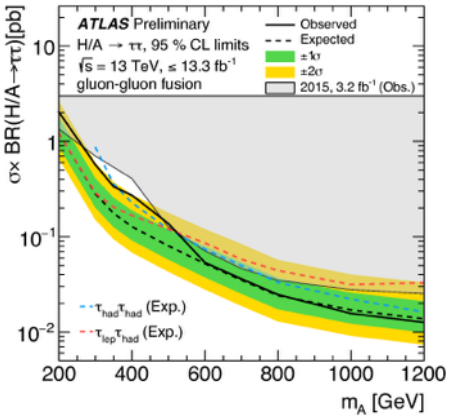
ggH

CMS also produced limits from associate b production and hMSSM scenario

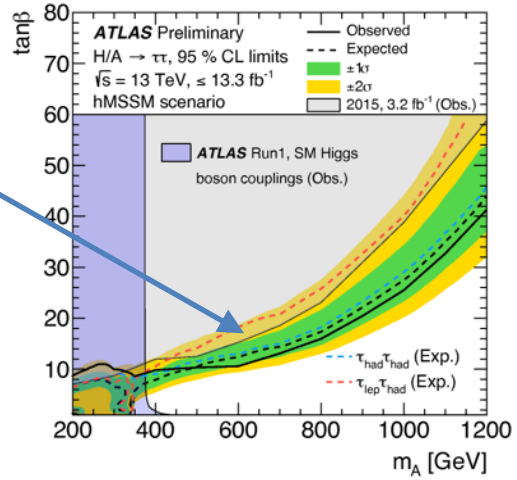


surpassing expected sensitivity from RunI starting from m_A~600GeV

- ATLAS: 13.3 fb^{-1} at 13 TeV
  - 2 channels: $\tau_{lep}\tau_h$, $\tau_h\tau_h$
  - 2 categories: 0 b-jet, ≥ 1 b-jet
  - ATLAS-CONF-2016-085



also limits from associate b production and MSSM m_h^{mod+} scenario



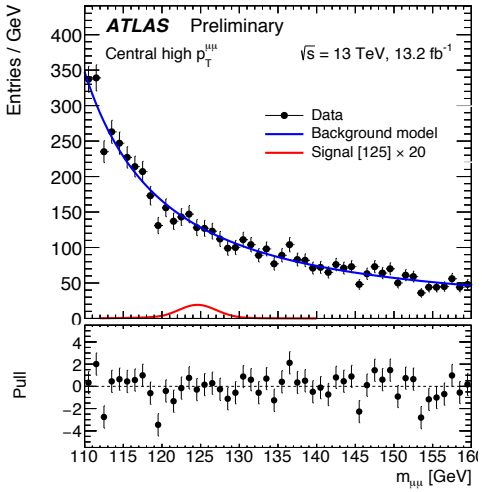
2015 result

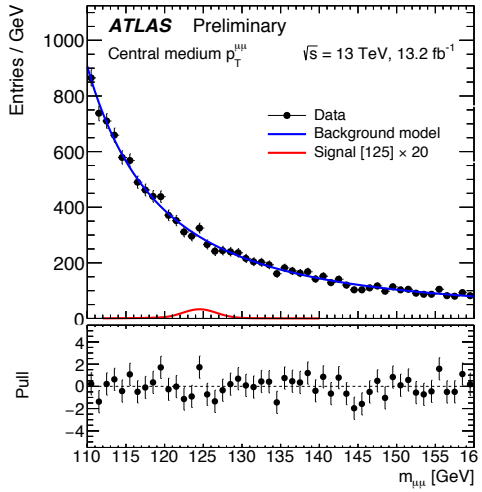
Summary

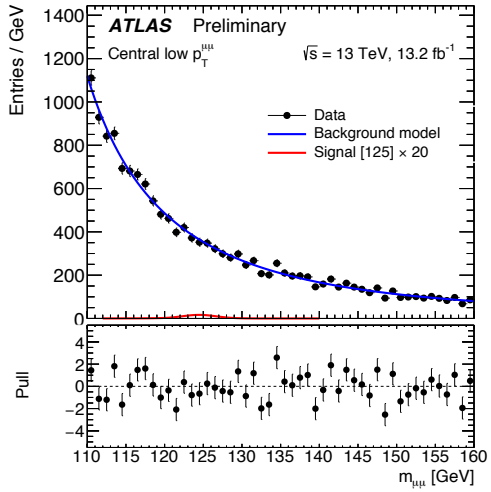
- many searches for Higgs rare decays
  - SM rare decay not yet observed
    - H→μμ, ee
    - H→Z/γ γ
    - H→J/ψγ, Yγ, Φγ
- BSM (Exotic) Higgs decays:
  - LFV decays of the Higgs has not been observed yet.
    - small fluctuation in H→μτ from 8TeV data not confirmed/excluded from 13TeV data. More statistics is needed
  - No evidence for invisible Higgs decays: B<25%
- Heavy Higgs boson fermion decays:
  - no excess above the SM expectation has been found searching for H→tt, H→bb, H →tb, H →τν, H→ττ
  - Upper limits on σ x B have been set
  - results have been interpreted in MSSM benchmark scenarios. New (13 TeV) limits surpassed those set during RunI for intermediate and high masses

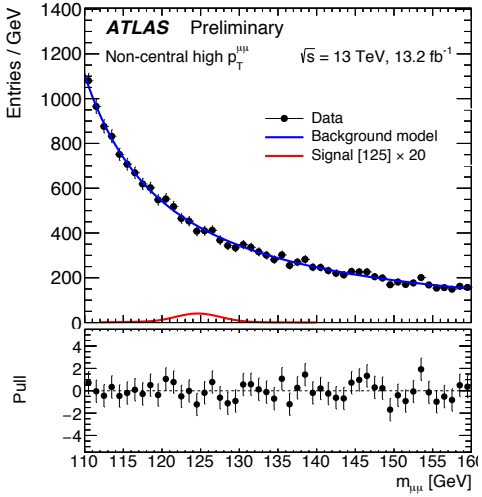
BACKUP

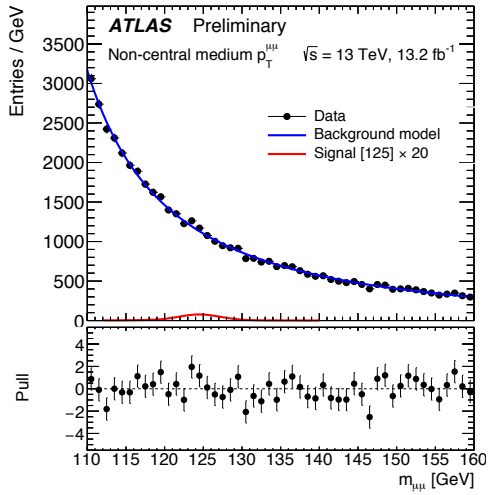
H→μμ

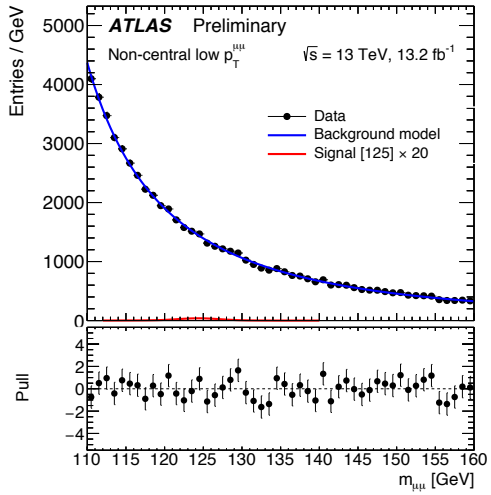

ATLAS Preliminary
Central high $p_T^{\mu\mu}$
$\sqrt{s}$ = 13 TeV, 13.2 fb^{-1}
Data
Background model
Signal [125] × 20
Entries / GeV
Pull
$m_{\mu\mu}$ [GeV]

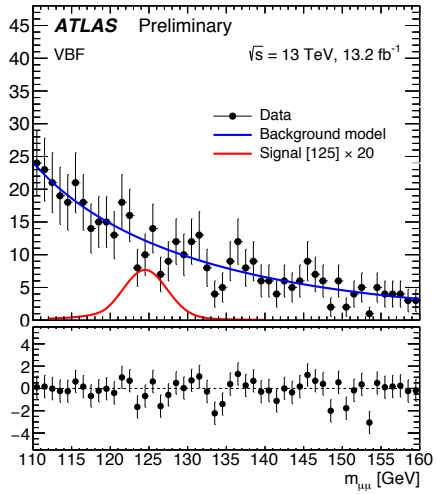

ATLAS Preliminary
Central medium $p_T^{\mu\mu}$
$\sqrt{s}$ = 13 TeV, 13.2 fb^{-1}
Data
Background model
Signal [125] × 20
Entries / GeV
Pull
$m_{\mu\mu}$ [GeV]


ATLAS Preliminary
Central low $p_T^{\mu\mu}$
$\sqrt{s}$ = 13 TeV, 13.2 fb^{-1}
Data
Background model
Signal [125] × 20
Entries / GeV
Pull
$m_{\mu\mu}$ [GeV]


ATLAS Preliminary
Non-central high $p_T^{\mu\mu}$
$\sqrt{s}$ = 13 TeV, 13.2 fb^{-1}
Data
Background model
Signal [125] × 20
Entries / GeV
Pull
$m_{\mu\mu}$ [GeV]


ATLAS Preliminary
Non-central medium $p_T^{\mu\mu}$
$\sqrt{s}$ = 13 TeV, 13.2 fb^{-1}
Data
Background model
Signal [125] × 20
Entries / GeV
Pull
$m_{\mu\mu}$ [GeV]


ATLAS Preliminary
Non-central low $p_T^{\mu\mu}$
$\sqrt{s}$ = 13 TeV, 13.2 fb^{-1}
Data
Background model
Signal [125] × 20
Entries / GeV
Pull
$m_{\mu\mu}$ [GeV]


ATLAS Preliminary
VBF
$\sqrt{s}$ = 13 TeV, 13.2 fb^{-1}
Data
Background model
Signal [125] × 20
$m_{\mu\mu}$ [GeV]

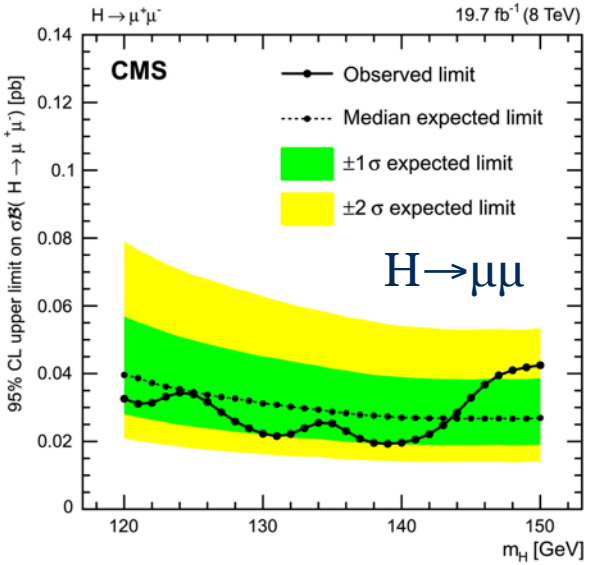
H→ee

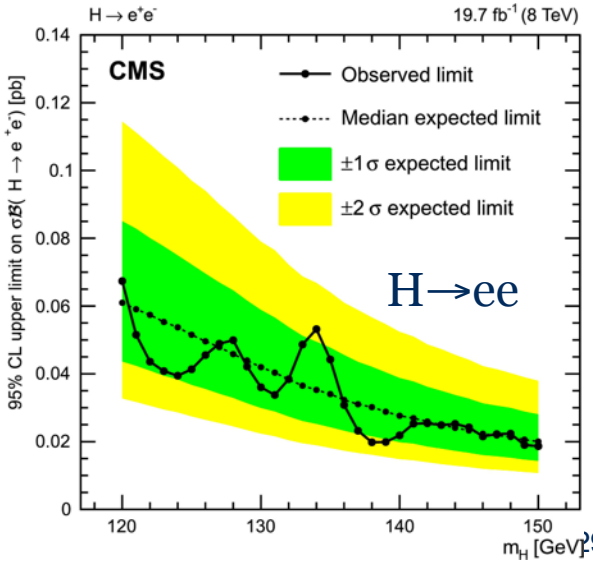
8 TeV

Phys. Lett. B 744 (2015) 184-207

CMS has performed the search of the decay to electron pairs using Run1 data.

- Extremely rare: branching ratio orders of magnitude less than H→μμ
- Similar sensitivity in term of cross-section times branching ratio

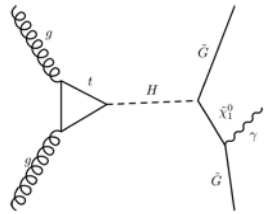


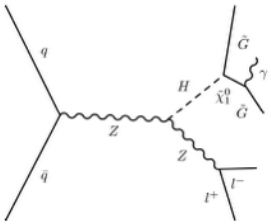


- CMS observed upper limit on σ(H)xB(H→ee):
  - σ(H)xB(H→ee) < 0.041 pb
- CMS upper limit on branching ratio:
  - B< 0.0019 (~3.7 x 10^5 SM B)

H→invisible + γ

8 TeV





- ggH and ZH production channels
- ggH: 2 analysis strategy
  - model dependent (SUSY)
  - model independent: 0 and 1 jets
- ZH: 2 lepton with opposite charge, same flavour, and mass of Z
  - Signal topology: Z(ll)+E_T^{miss}
- No excess observed

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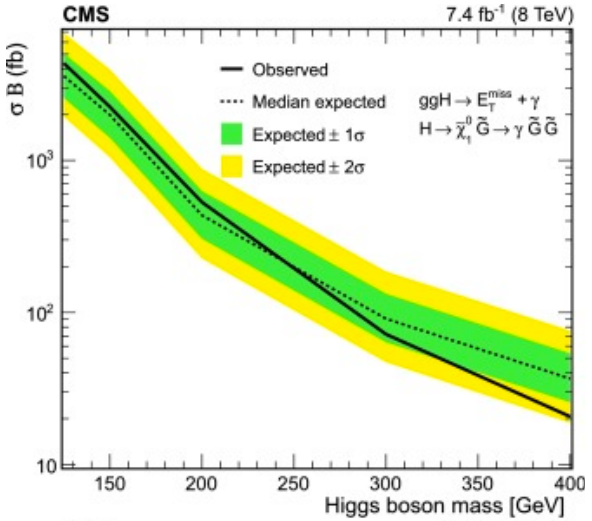
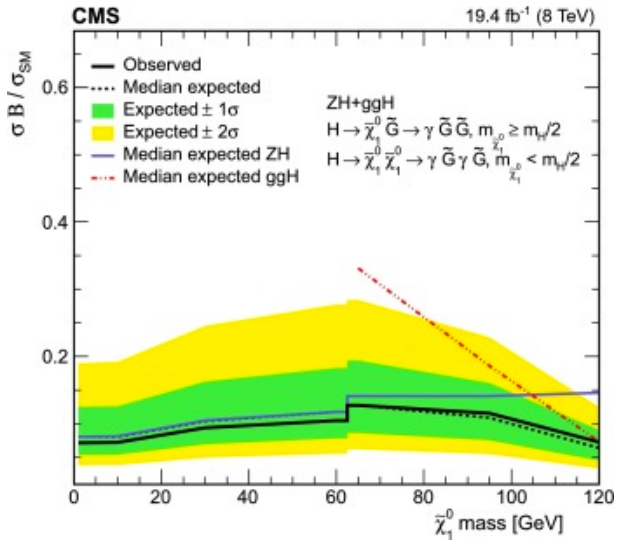
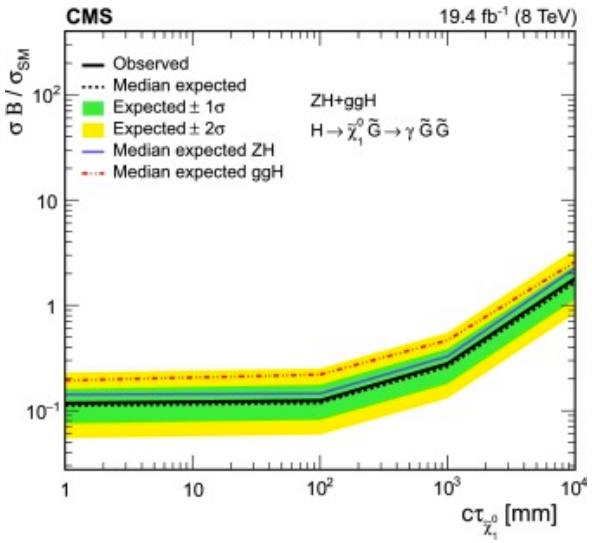
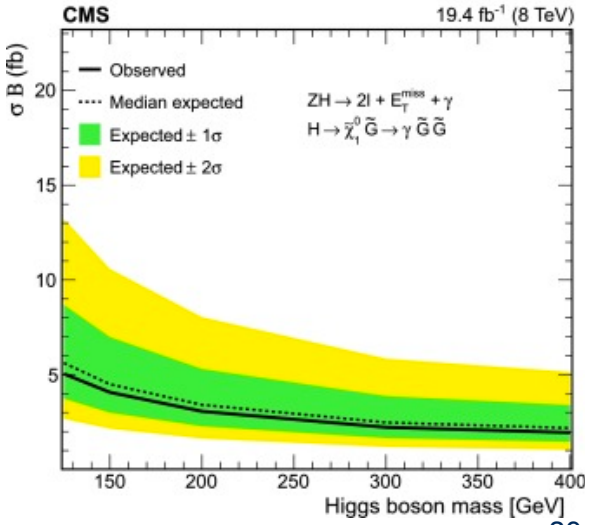




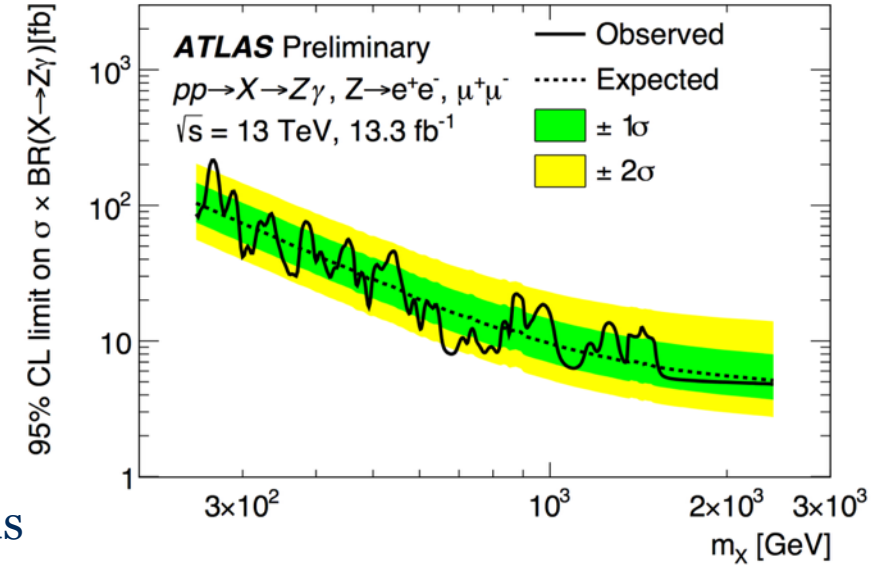




New resonance → Zγ

ATLAS EXPERIMENT

- ATLAS searched for new resonance with a mass [ATLAS-CONF-2016-044]
  - 250 GeV < m_X < 2.4 TeV
  - 13.3 fb^{-1} at 13 TeV
  - Z→ee, μμ



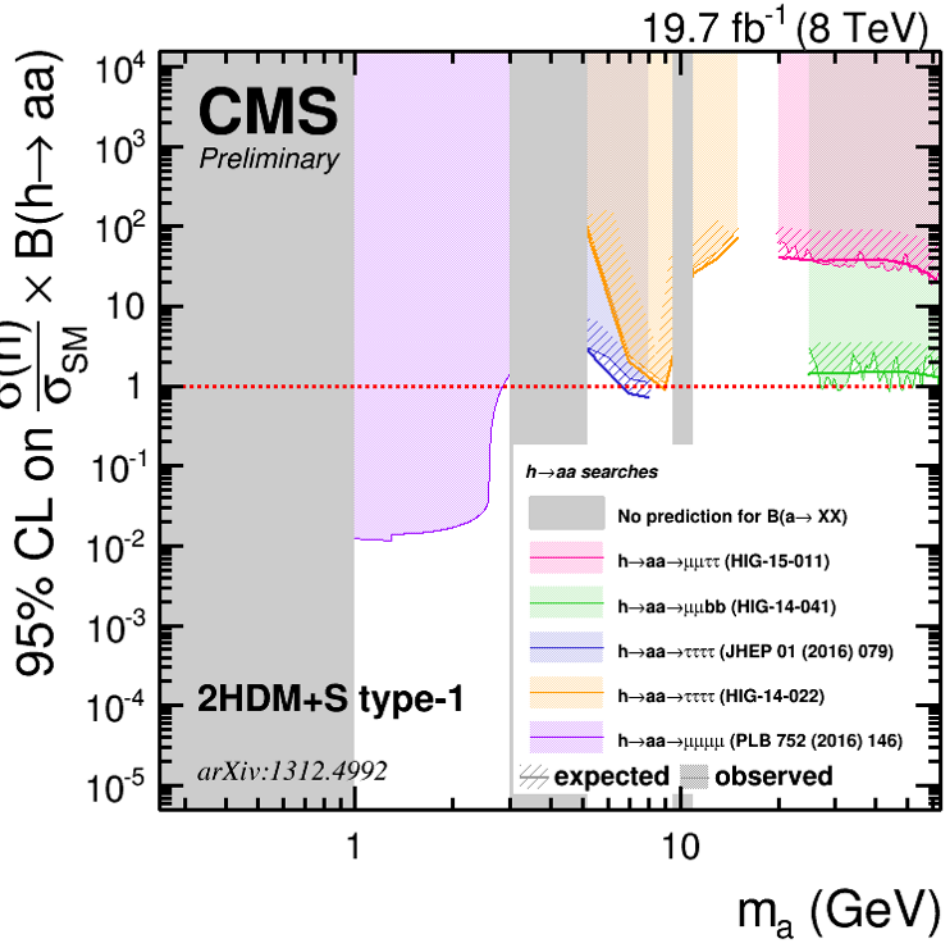
- No excess observed
- largest deviation from background only:
  - 2.2 σ at m_X=268 GeV

- Dominated by stat uncertainty
- Main contribution to the syst. uncertainty:
  - electron and photon resolution, spurious signal , luminosity uncertainty

- Observed limit on cross section:
  - from 215 fb for m_X=270GeV to 5 fb for m_X=2.4 TeV
- Expected limit:
  - from 103 fb for m_X=270 GeV to 5 fb for m_X=2.4 TeV

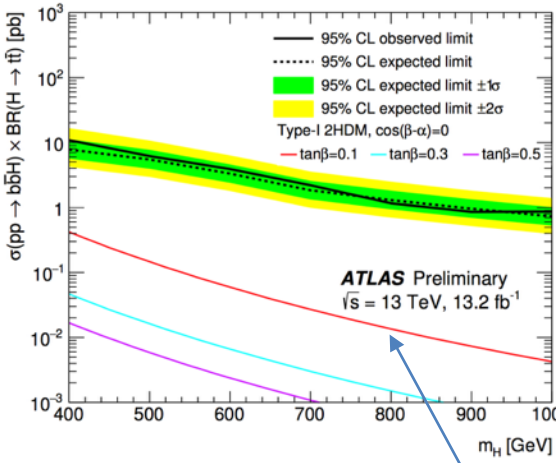
H→aa

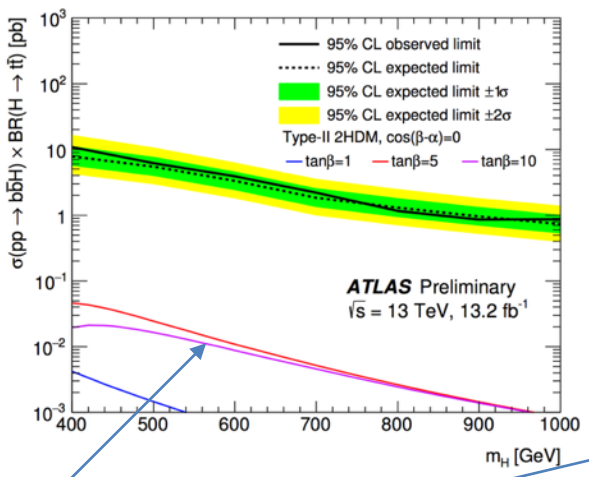
8 TeV


19.7 fb-1 (8 TeV)
CMS
Preliminary
95% CL on σ(h)/σSM × B(h→ aa)
2HDM+S type-1
arXiv:1312.4992
h→aa searches
No prediction for B(a→ XX)
h→aa→μμττ (HIG-15-011)
h→aa→μμbb (HIG-14-041)
h→aa→ττττ (JHEP 01 (2016) 079)
h→aa→ττττ (HIG-14-022)
h→aa→μμμμ (PLB 752 (2016) 146)
expected
observed
ma (GeV)

New phenomena in tt final states

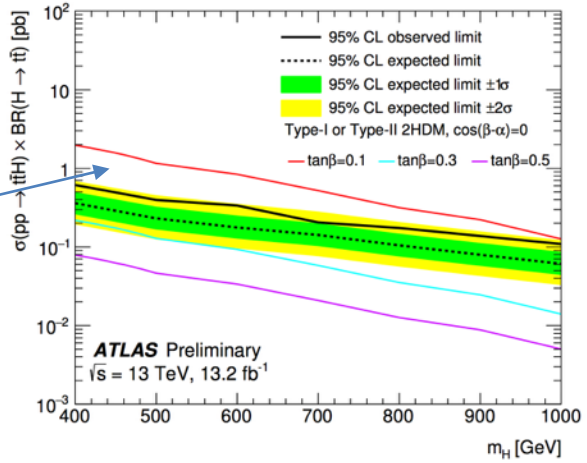
- ATLAS searched for new phenomena in tt final states using 13.2 fb^{-1} of collision data at 13 TeV:
  - vector like top quark (T) to a top quark and either a H or Z
  - 4 top quark production
  - heavy Higgs bosons (neutral and charged) in association with and decaying to 3rd generation quarks





theoretical prediction assuming cos(β-α) =0

- 1 isolated lepton with high p_T: μ or e
- multiple jets
- high missing transverse energy



ATLAS-CONF-2016-104

H→cb

8 TeV

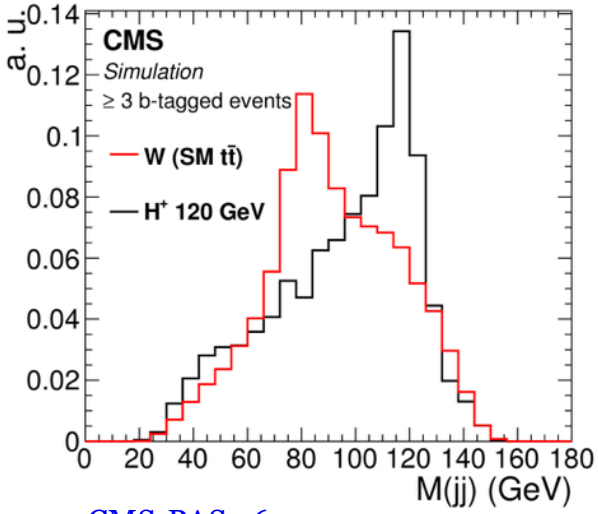
CMS looked for $H^+ \to c\bar{b}$

- enhanced and dominant decay in type-Y 2HDM model

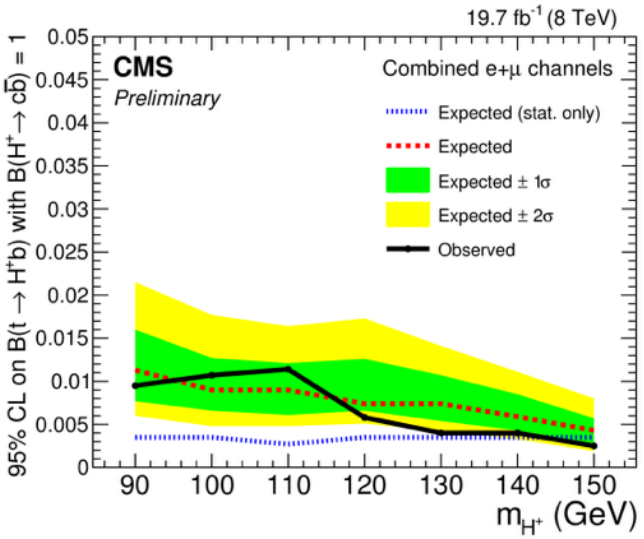
- Looked for in $t\bar{t}$ production
  - $t \to H^+ b \to c\bar{b}b$
  - $\bar{t} \to W^- \bar{b} \to l\bar{\nu}b$
  - 4 jets events (3 b-tagged) + lepton and MET

- 4 categories depending on the number of b-jets and lepton flavour
- max likelihood fit to the binned M(jj) templates, assuming $B(H^+ \to c\bar{b})=100\%$

- 95% CL upper limit:
  - 1.1-0.4 % for M(H+)=90-150 GeV

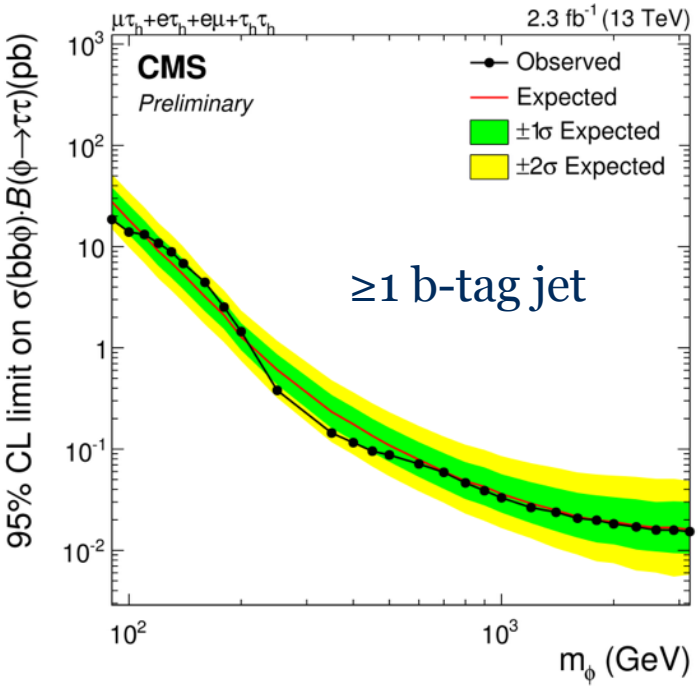


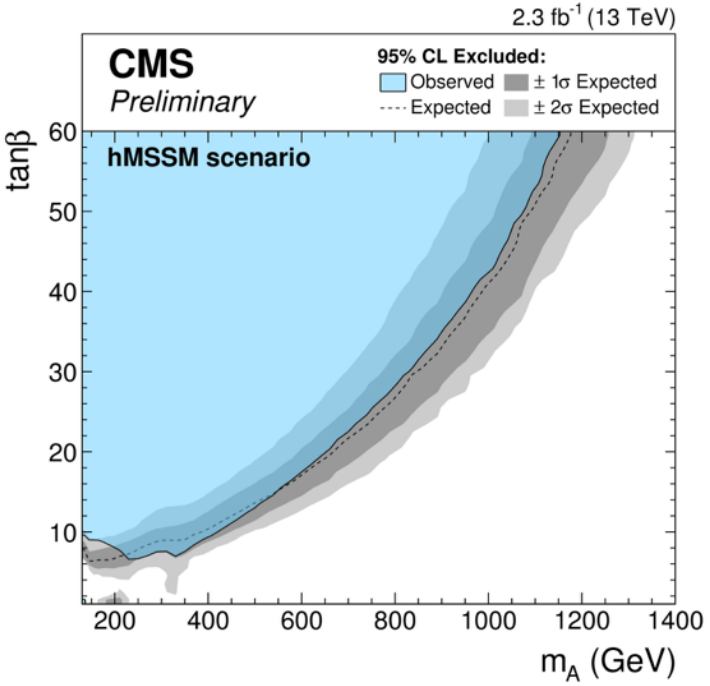
CMS-PAS-16-030



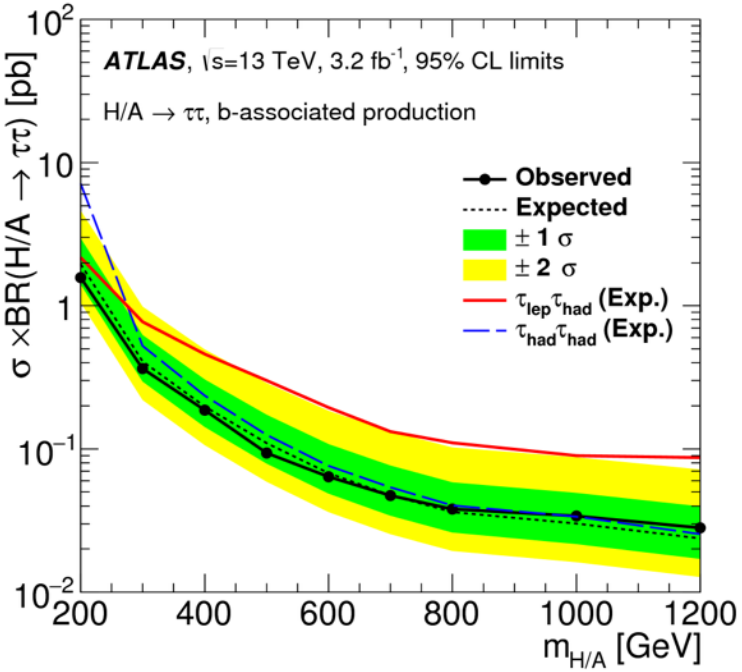
H/A →ττ

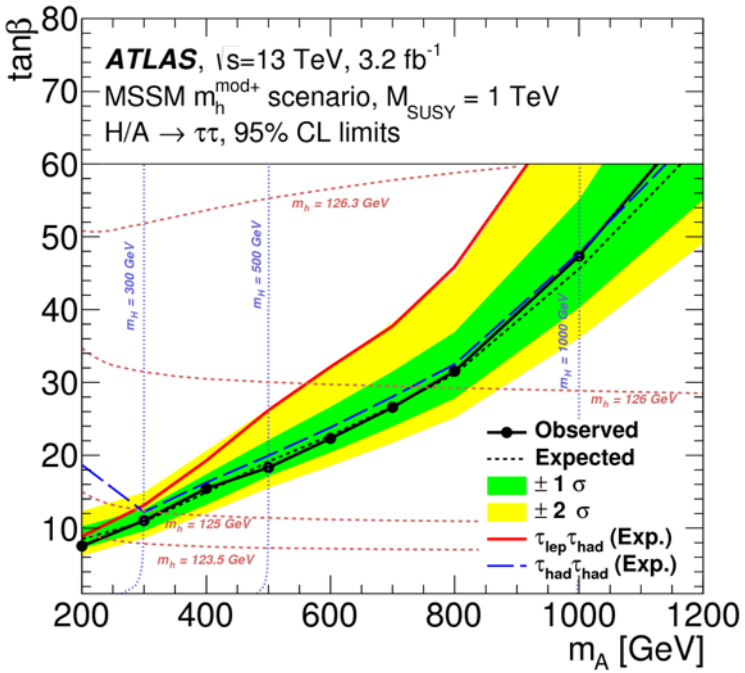
- CMS-PAS-HIG-16-006





H/A → ττ





- arXiv:1608.00890