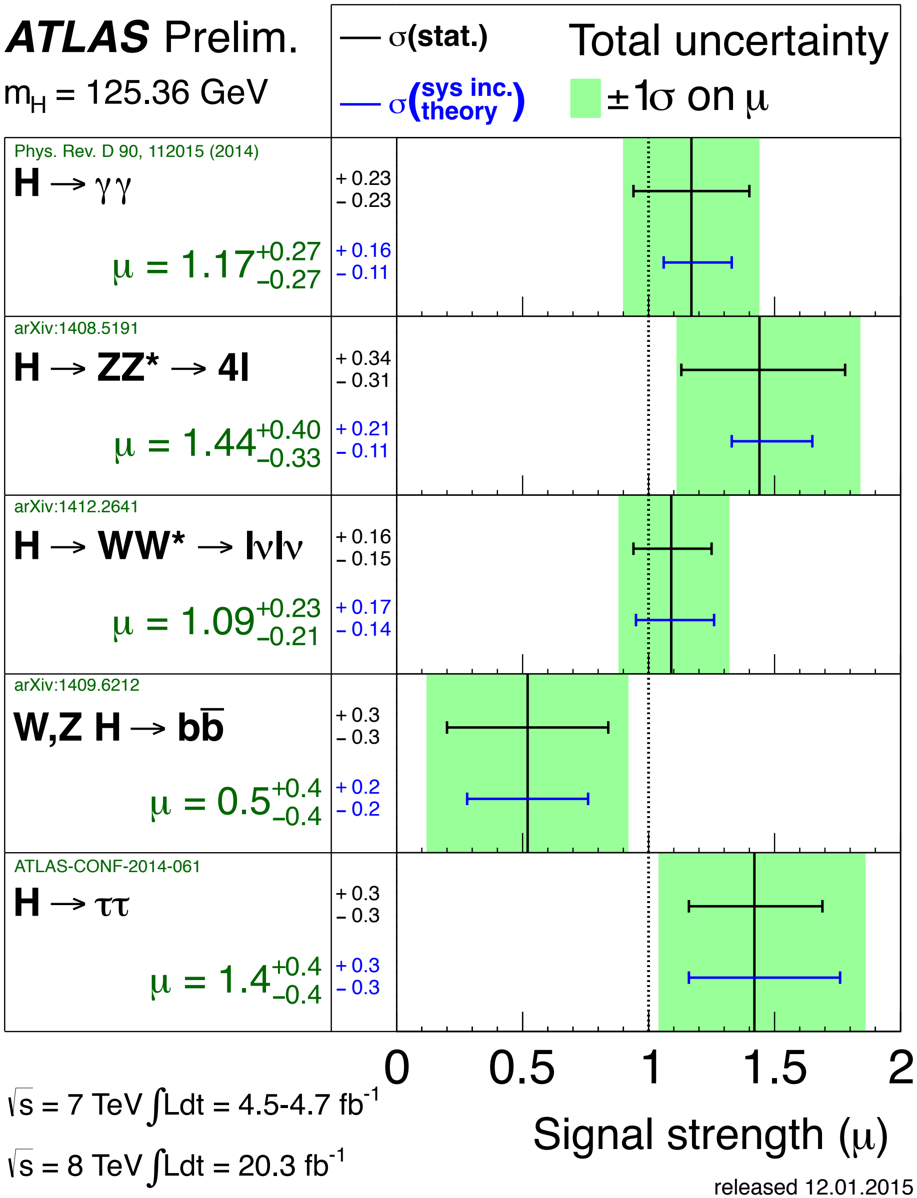
HBSM at the LHC

Jahred Adelman

On behalf of the CMS and ATLAS collaborations



Looks very much like SM-Higgs boson. So where will we find new physics?

- Nothing says there has to be only one Higgs boson
  - Same Higgs boson leads to EWSB and also gives mass to fermions?
  - Extra Higgs boson motivated by SUSY but other areas of physics too (models with axions, baryogenesis, neutrino masses)
- Haven't seen new physics elsewhere yet
- Lots of reasons that SM needs extension
  - Hierarchy problem
  - Dark matter
  - ...

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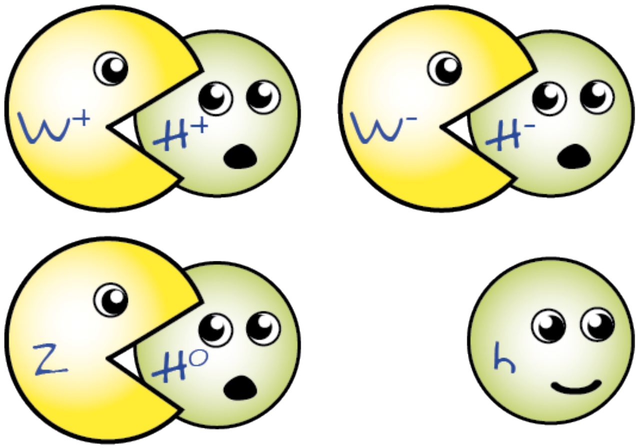
- **Look for new Higgs bosons**
  - General structure typically Two Higgs Doublet Model (2HDM)
- Higgs boson + invisible/dark sector
  - Higgs → invisible and dark sector analyses
- Higgs decays otherwise not allowed in SM
- New physics in Higgs boson pair production
- Discrepancies in couplings
  - production cross sections/branching ratios (not this talk)
- Discrepancies in kinematics
  - not at that level yet except to confirm JP nature of Higgs (not this talk)

SM Higgs field: Complex scalar doublet

4 degrees of freedom of which:

- 3 provide longitudinal components of $W^{\pm}$, Z
- 1 CP-even Higgs boson (h)



2HDM Higgs field: Two complex scalar doublets

8 degrees of freedom (4 more than usual):

- 2 CP-even Higgs bosons (h,H), one of which is the observed 125 GeV resonance
- CP-odd pseudoscalar A
- Two charged Higgs bosons $H^{\pm}$

- Four Higgs boson masses (m_H, m_h, m_A, $m_{H^\pm}$)
  - m_H or m_h = 125 GeV
- Ratio of the vacuum expectation values of the two doublets, $\tan\beta = v_2/v_1$
- Mixing angle α of h and H
- $\cos(\beta-\alpha) \to 0$ = alignment limit, H doesn't couple to V

2HDM Type	Up-type quarks couple to...	Down-type quarks couple to...	Charged leptons couple to...
Type I	Φ_2	Φ_2	Φ_2
Type II	Φ_2	Φ_1	Φ_1
Lepton-specific	Φ_2	Φ_2	Φ_1
Flipped	Φ_2	Φ_1	Φ_2

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- MSSM (Mimimal Supersymmetric Standard Model) is an instance of Type II 2HDM
- NMSSM (Next-to MSSM) is an extension of MSSM that adds an extra gauge singlet
  - Solves μ-problem (fine-tuning) of MSSM
  - Gain extra CP-even and CP-odd Higgs bosons

2HDM Type	Up-type quarks couple to...	Down-type quarks couple to...	Charged leptons couple to...
Type I	Φ_2	Φ_2	Φ_2
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Flipped	Φ_2	Φ_1	Φ_2

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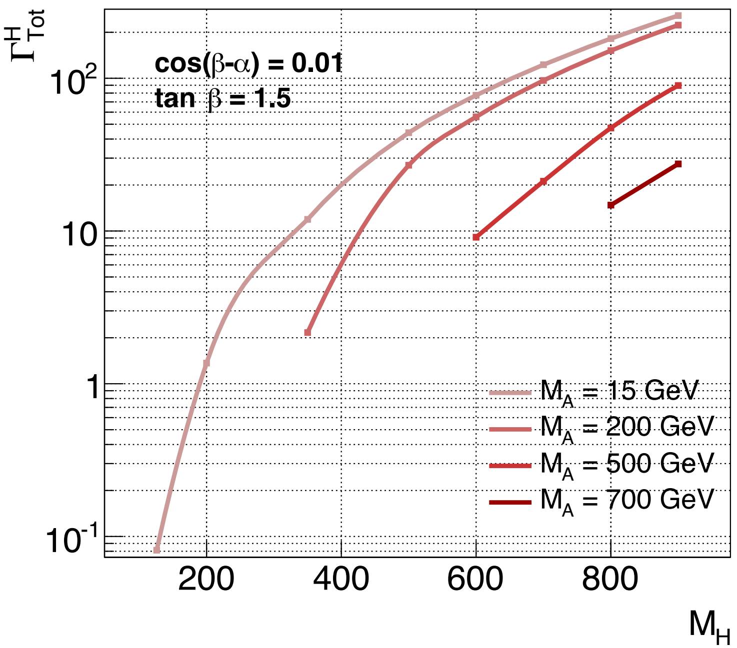
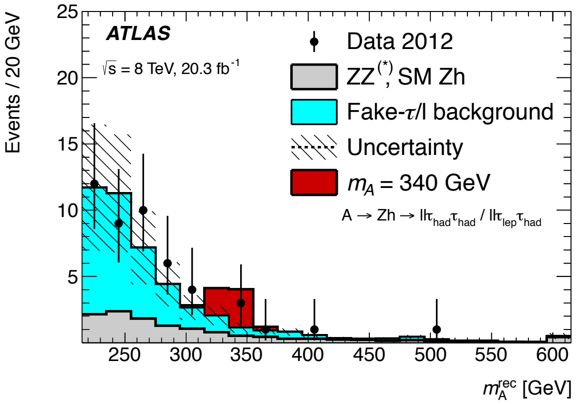
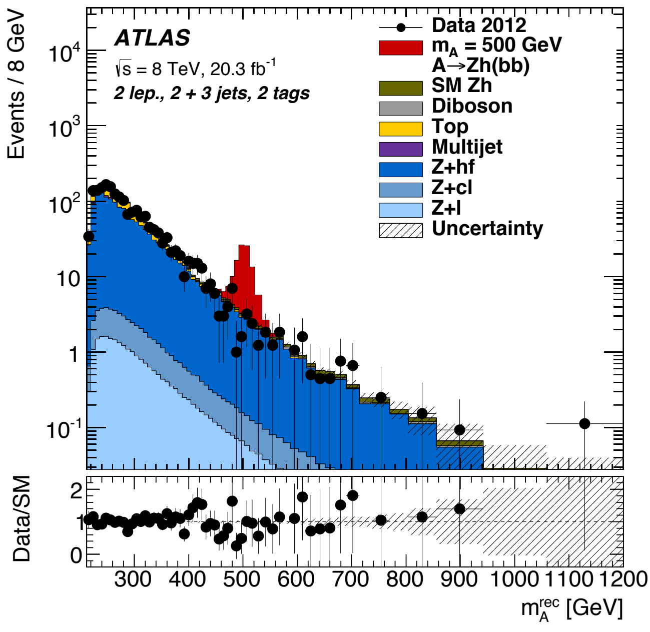
- Look for decays of new, heavy Higgs bosons to 125 GeV Higgs + Z boson
- Take advantage of Z→ll and Z→νν decays
- Use highest branching ratio Higgs boson decays (bbbar / ditau)
- Typically use knowledge of masses of Z/h to select events, constrain the system (and improve 4-object mass resolution)



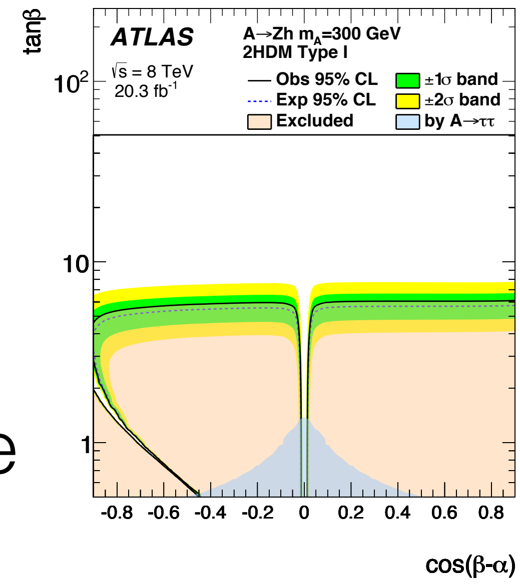
- h→$\tau\tau$, Z→ll
  - Separate based on number of hadronic tau decays
  - Shape of hadronic tau fake from events with SS taus or taus failing ID cuts, normalized using mass sidebands

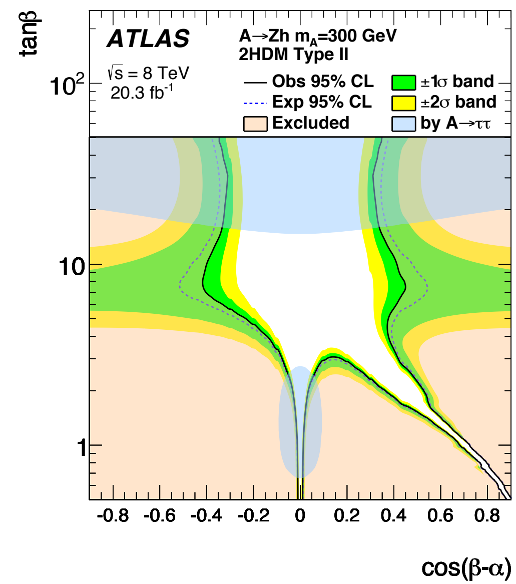


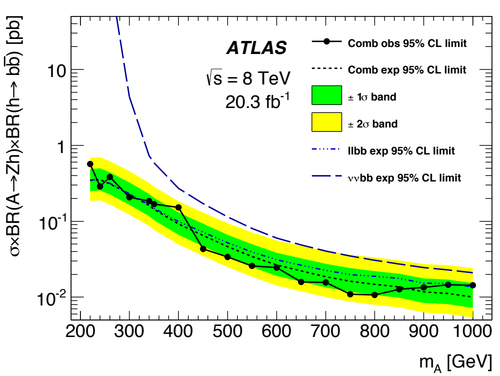
- h→bb, Z→ll and $\nu\nu$
  - For neutrino decays of Z boson, require large calorimeter and track MET, angular cuts to suppress multijet background, use transverse mass instead of m_A
  - Multijet backgrounds: μμbb neglible, eebb estimated by fitting m_{ll} to templates with inverted isolation, $\nu\nu$bb estimated by inverting cuts on track vs calo MET, normalized by inverting angular cuts
  - V+HF constrained with V+0/1 btag vs njet

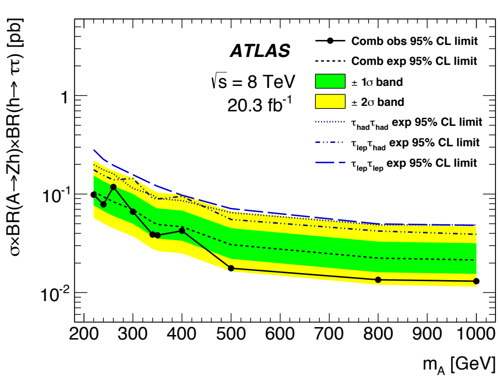


- Non-zero widths larger than mass resolution up to 5% of m_A taken into account
- No evidence for new physics (will be a common theme)

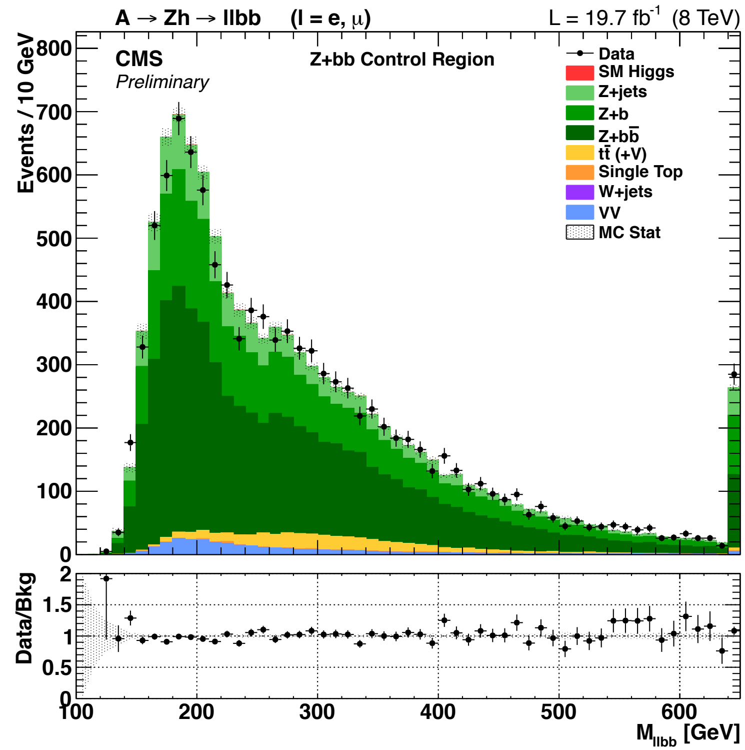


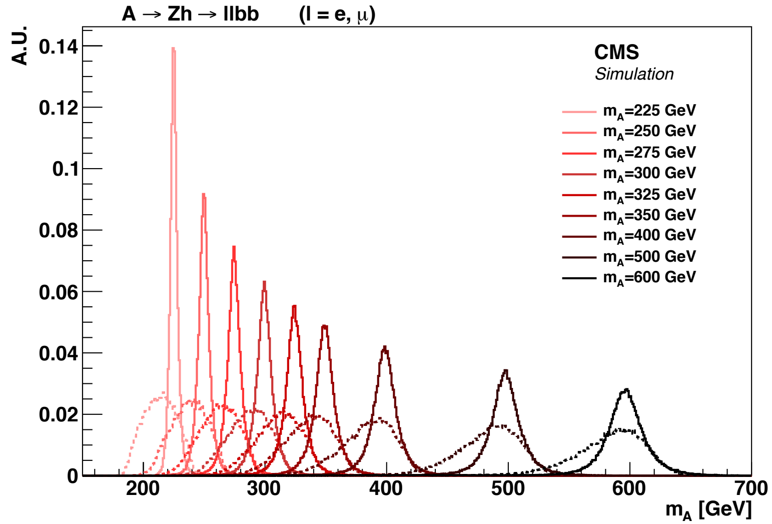




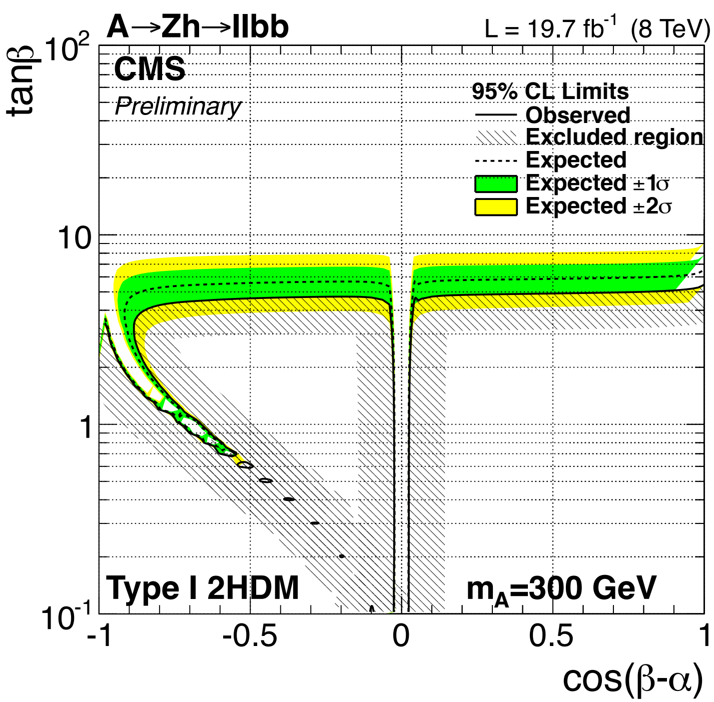


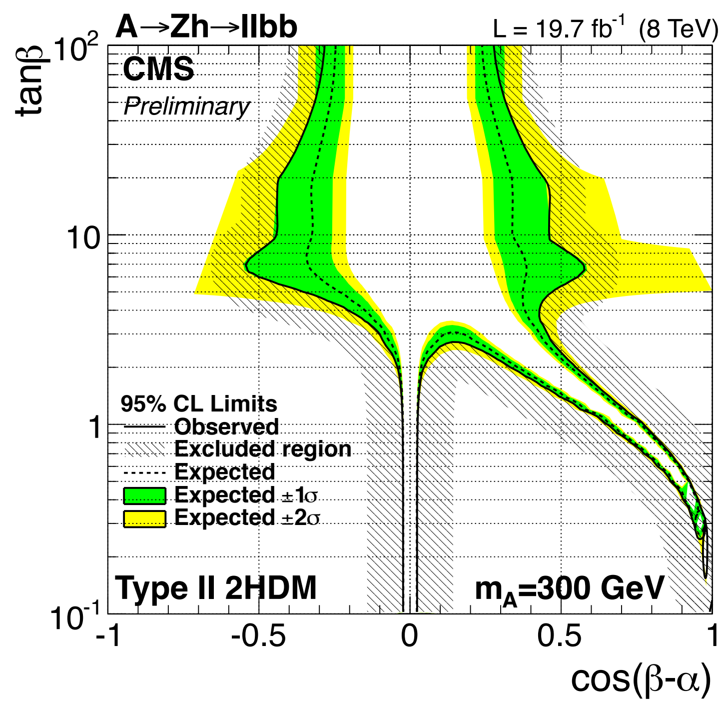
- Use loose+tight b-tagging
- Check Z+heavy flavor in regions with 0/1/2 btag but m_{bb} far from m_H
- Multijet events negligible
- Kinematic fit to improve mass resolution (scale p_T and angles of jets)
- Multivariate BDT trained separately for low/medium/high m_A to discriminate S vs B
- Results from fit to 2D distribution of BDT and m_{llbb}



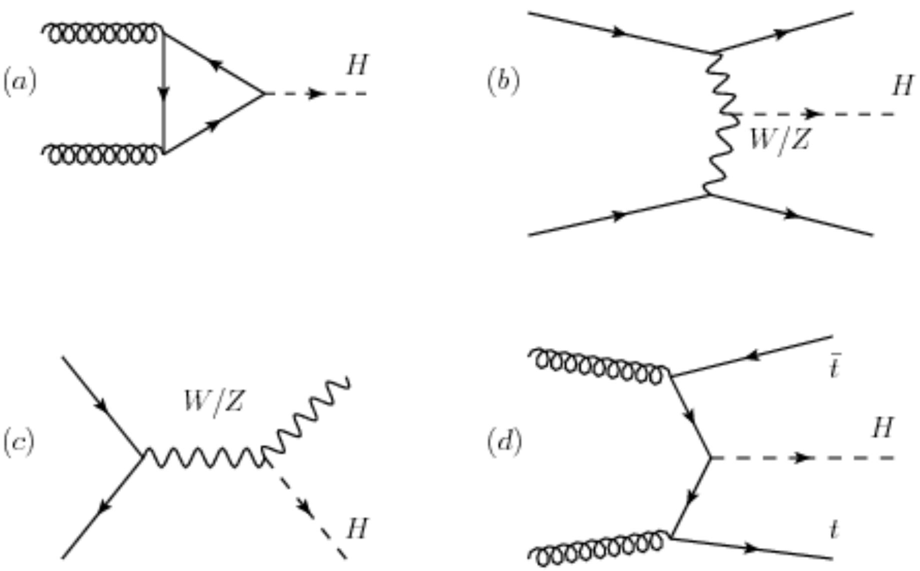


BDT adding significant additional information: Using 1D fits worsens limits by 10-20%

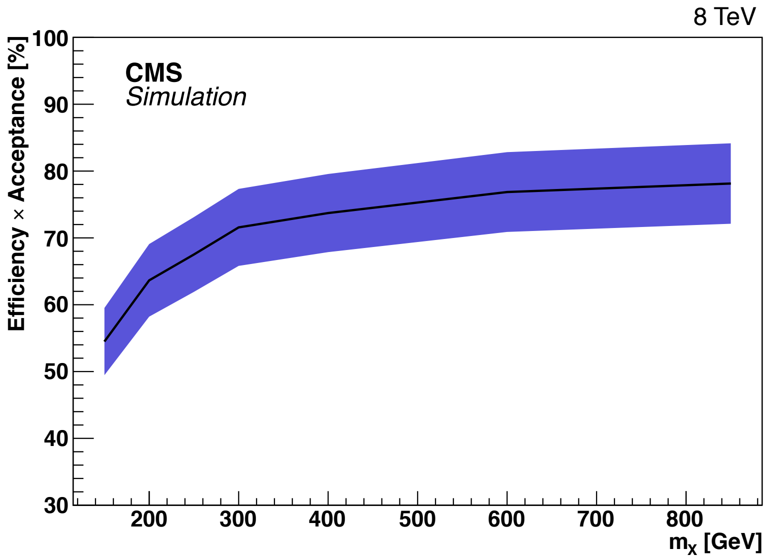


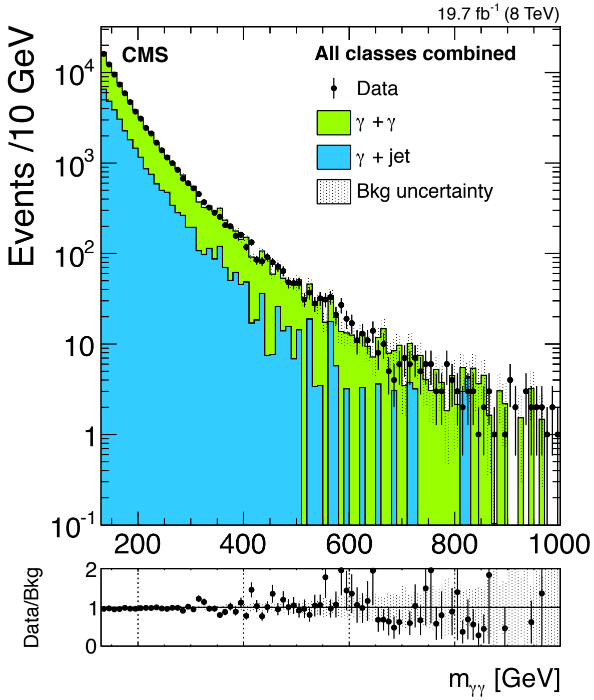


- Can use 2HDM as benchmark to search for other new resonances
- Often (but not always) searching for something heavier than 125 GeV
- Take advantage as always of many production modes
- Orthogonal to previous Z/A searches, helps to expand limits on 2HDM parameter space

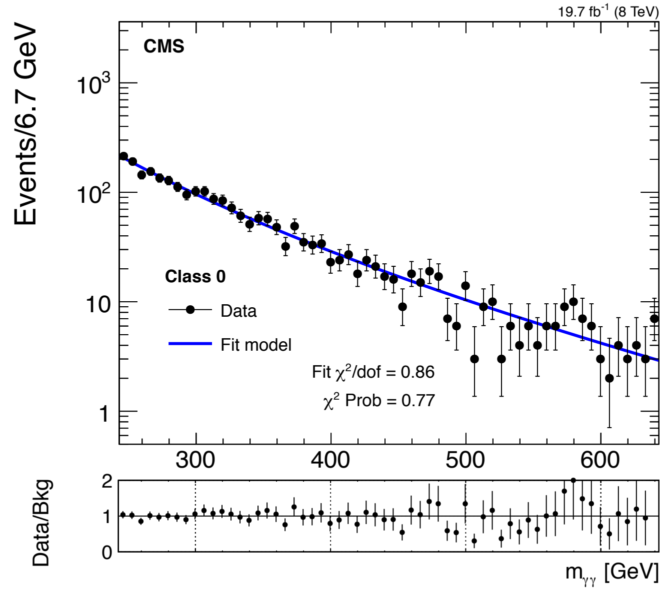


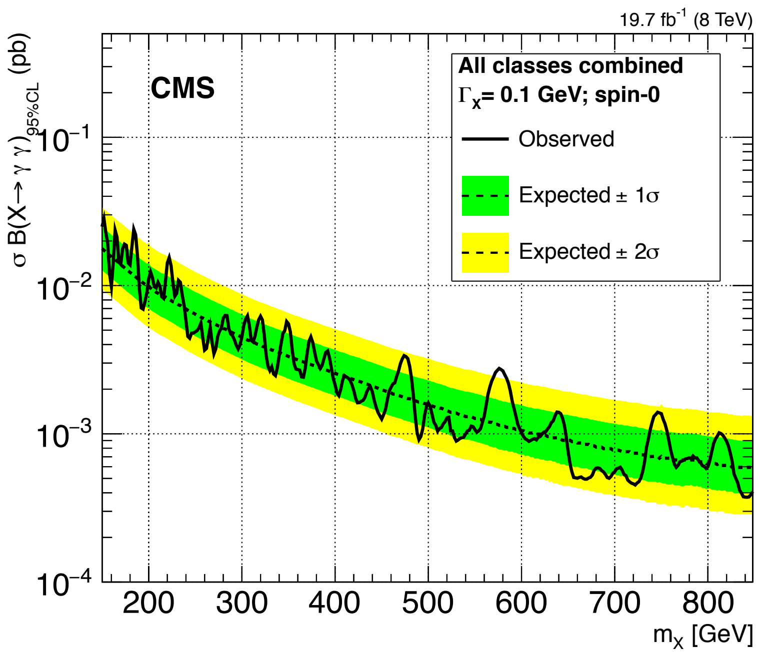
- Seeded by ~efficient loose diphoton triggers (look for ggF production)
- Require two high-E_T, isolated photons using various track- and calorimeter-based variables and different cone sizes
- Divide events based on photon quality and maximum photon |η|
- Fit diphoton mass distribution to S +B, background modeled with 5 analytic functions to check for spurious signal
- Fit range varied to minimize bias for each resonance mass hypothesis

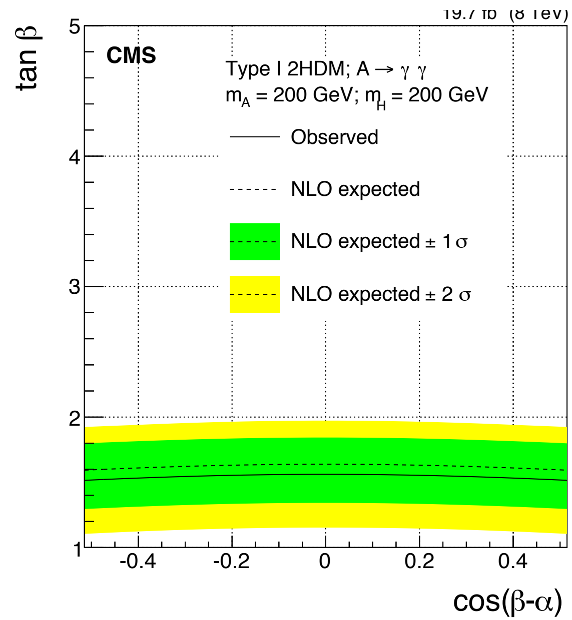




- Model signal with Crystal Ball, accounting for width up to 10% of resonance mass
- Separate limits on spin-0 and spin-2 resonances, plus 2HDM interpretation

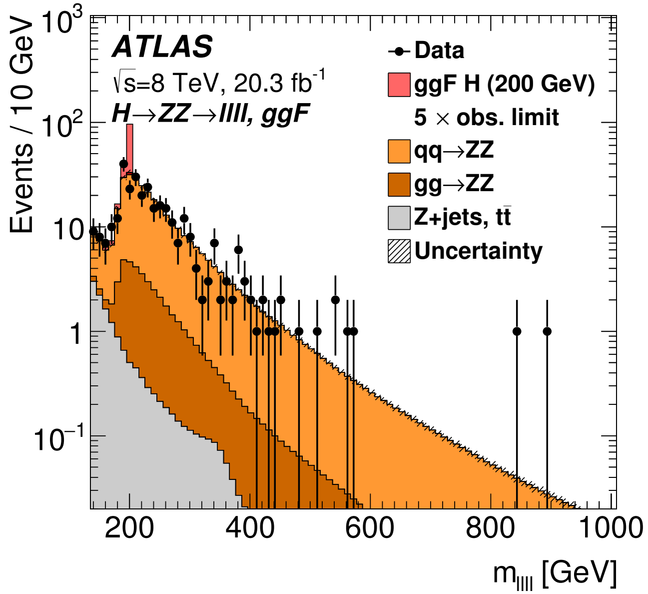


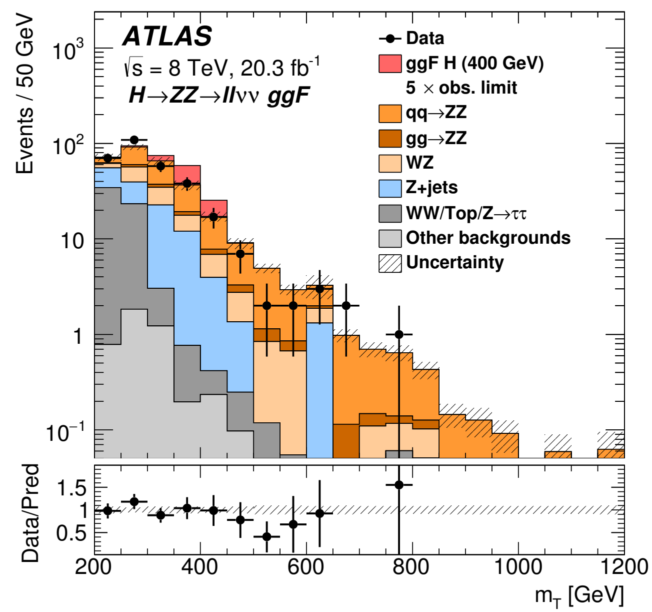




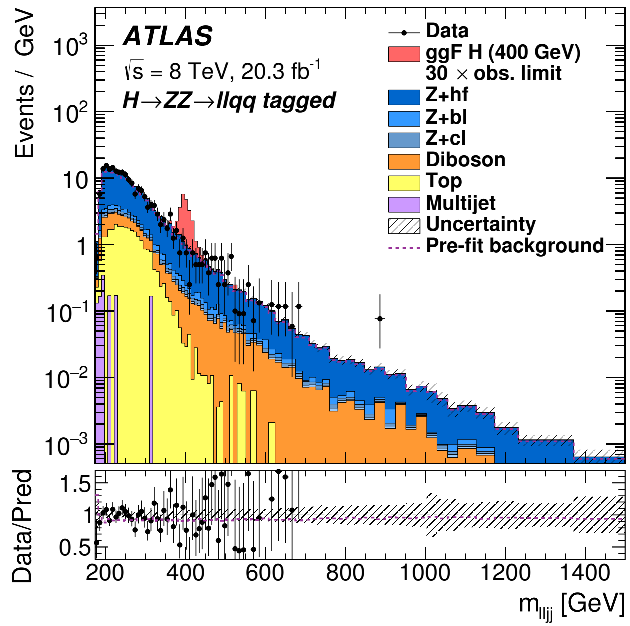
ATLAS results (low and high mass): 1407.6583

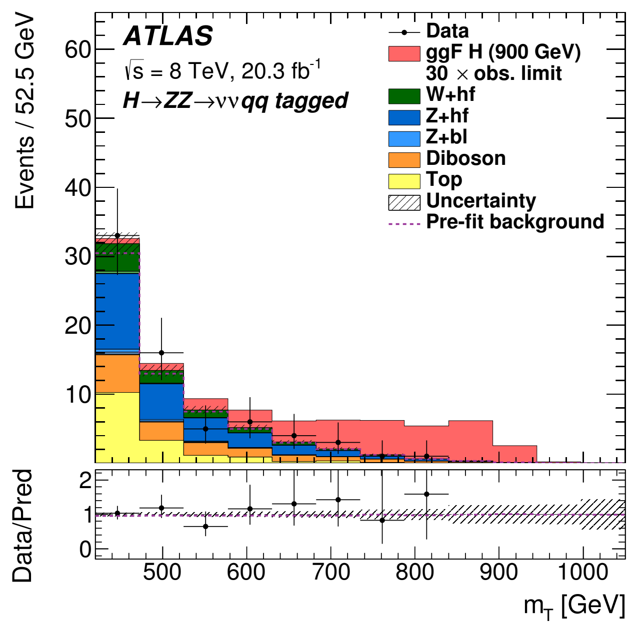
- Use ZZ→4l, ll$\nu\nu$, llqq and $\nu\nu$qq final states in ggF and VBF production modes (also llqq boosted), use lepton or MET triggers
- 4l: kinematic fit to Z hypothesis. Classify into VBF (forward jets w/large m_{jj}), VH (dijet mass or extra leptons) or ggF
  - Z+fake μμ estimated from data by fitting m_{ll} with inverted d0 cut and no isolation
  - Z+fake ee contribution estimated from data by relaxing calo ID, isolation and d0 cuts, and fitting to number of pixel and transition radiation hits
- ll$\nu\nu$: Classify into VBF or ggF, reject events with b-tags
  - tt background estimated from eμ data
  - Z+jets estimated from ABCD method: $\Delta\Phi$(ll, MET) and $\Delta\Phi$(l,l)





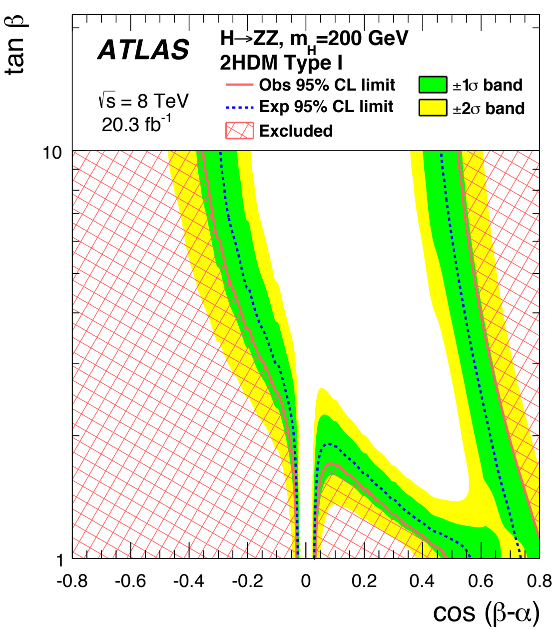
- llqq: Classify into VBF or ggF, as well as number of b-tags, reject events with high MET-significance
  - Scale dijet mass to Z mass
  - Merged jet ggF category requires high-p_T Z
  - Z+jets normalization from dijet sidebands (tagged vs untagged, b vs c vs LF)
  - tt background cross-checked in eμ data
- $\nu\nu$qq: Divide into nb-tags < 2/== 2
  - V+jets normalized as in llqq, checked in signal region with one/two very loose muons
  - tt background as in llqq

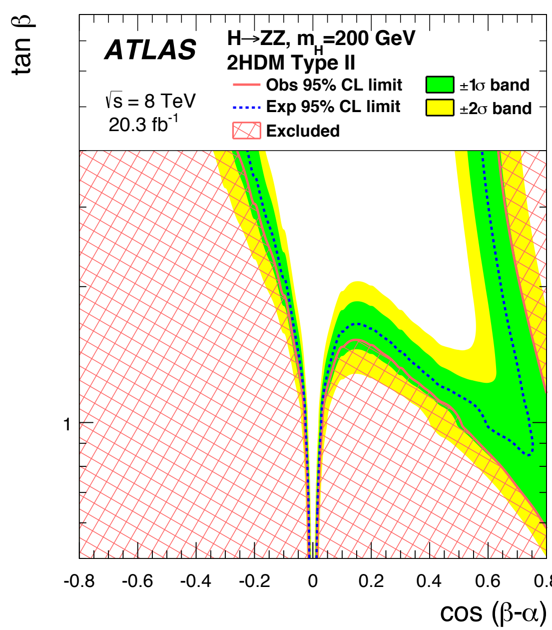


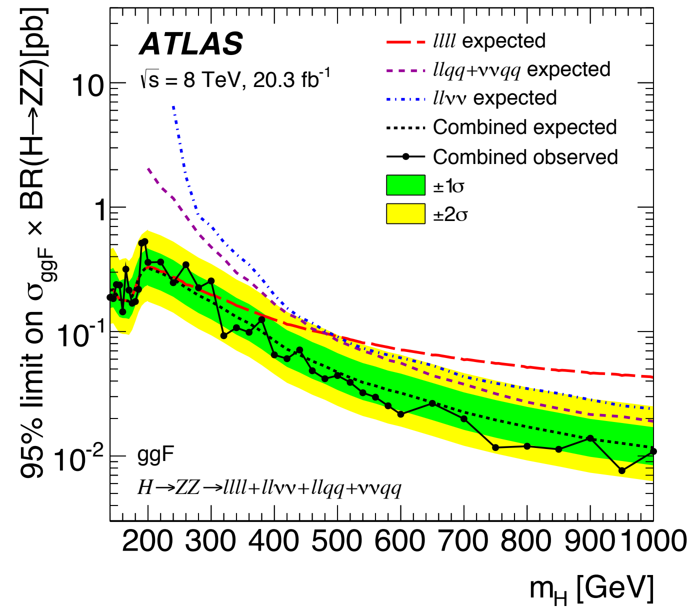


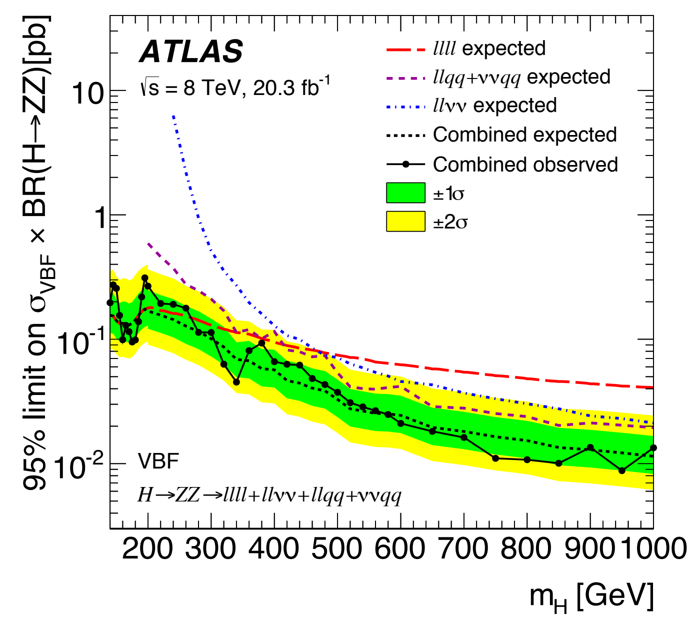
- The ggF and VBF relative ratio not fixed to SM
- Use m_H (or m_T) as discriminating variable

See 1509.00389 for H→WW (EWS model)

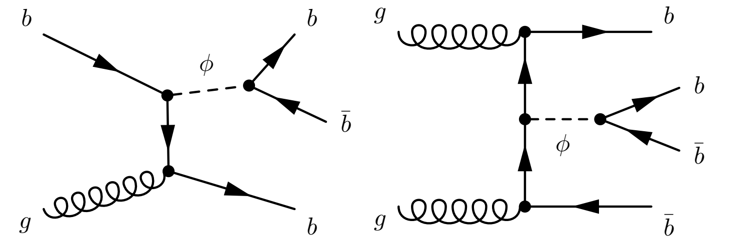


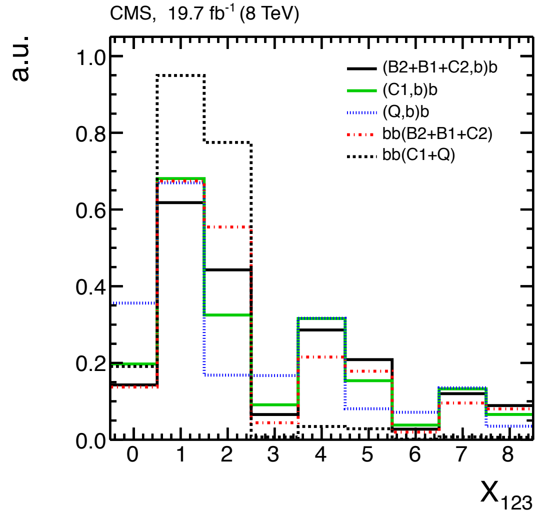


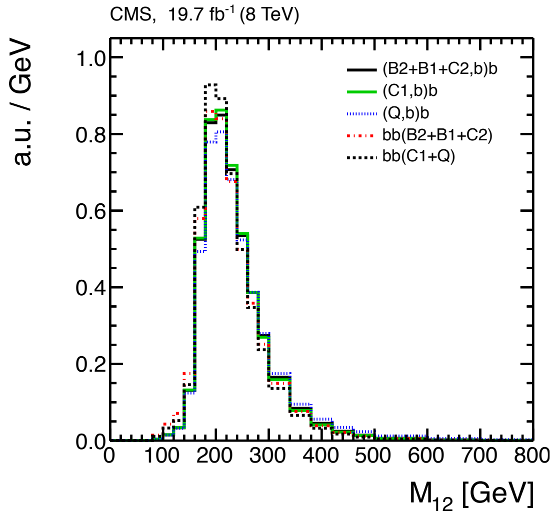




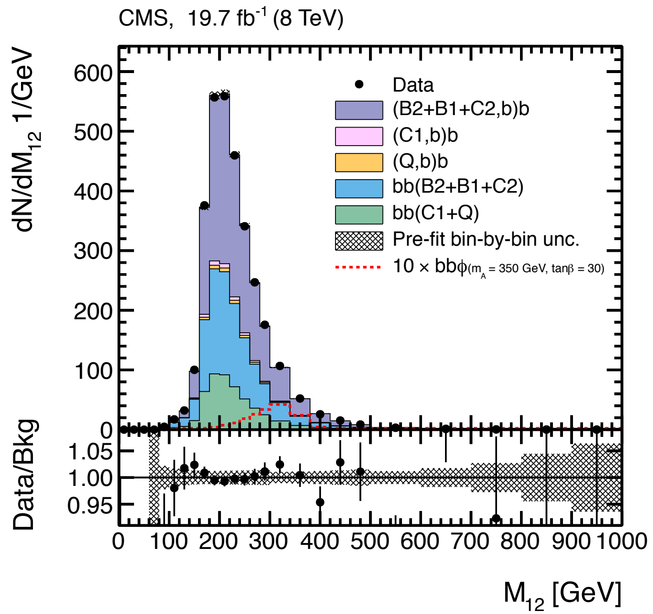
- Three neutral MSSM Higgs boson denoted by ϕ, enhanced bb decays at large tanβ
- Require two or more high-p_T b-tagged jets are trigger level, 3 tight b-tags offline
- Dijet mass resolution → single mass search is enough for fits
- ttbar expected to be tiny compared to QCD
- Use sum of secondary vertex masses within a jet for further categorization (X_{123})
- Form templates for 2b, 1b, 2c, 1c, LF jets in two-tag data events depending on which of 3 jets is untagged, further binned by X_{123} and leading dijet mass (M_{12})
  - Merge templates where appropriate and shapes are similar
  - Take assumed flavor weight from simulation
- Binned M_{12} and X_{123} used to fit signal + background

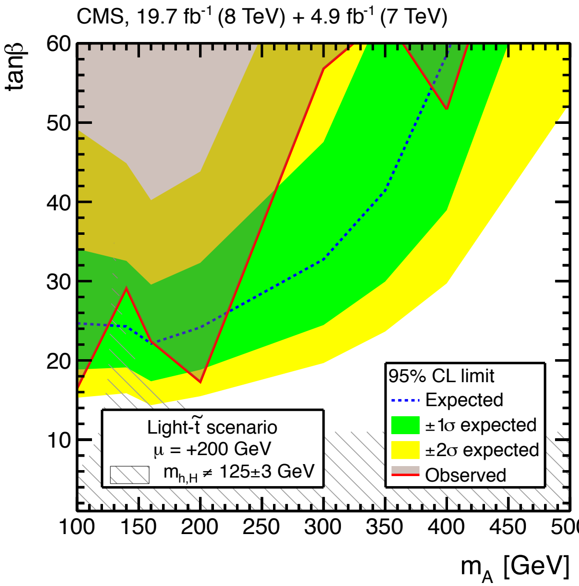


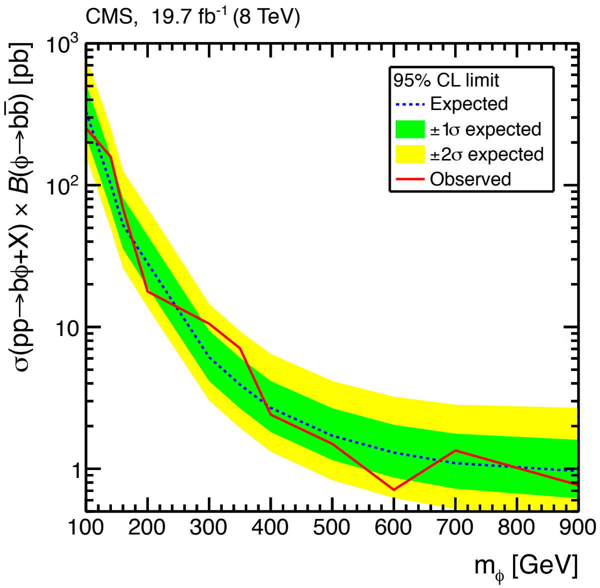


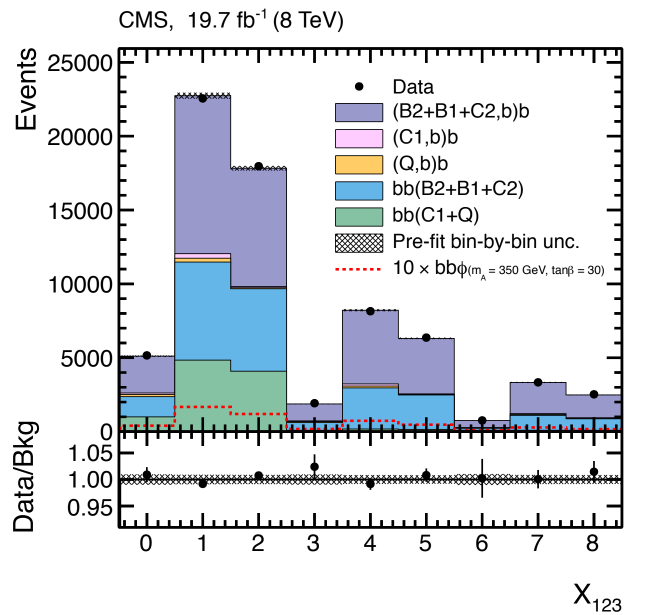


- Fit for generic cross section limits and also to various MSSM benchmarks for b-associated production
- Shown are 1D distributions unfolded after 2D fit



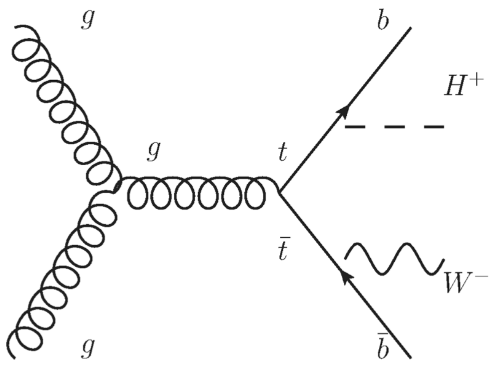




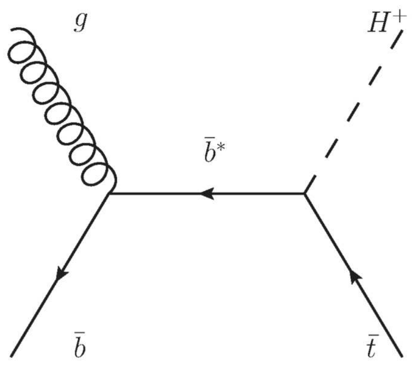


- 2HDM and other extensions predict Higgs bosons with electric charge
- Different types of decays than in neutral Higgs searches

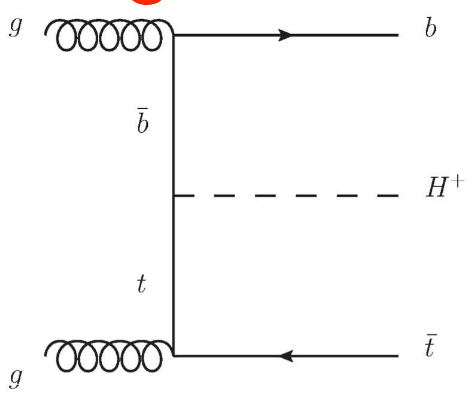
Low-mass



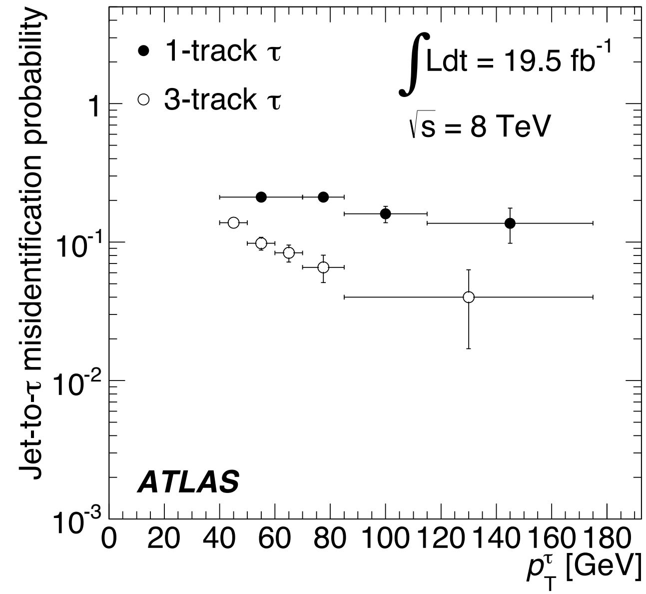
High-mass

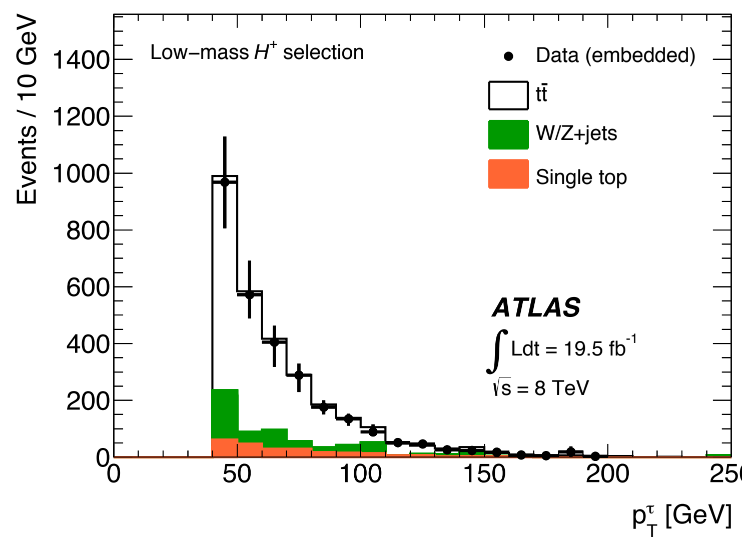


High-mass

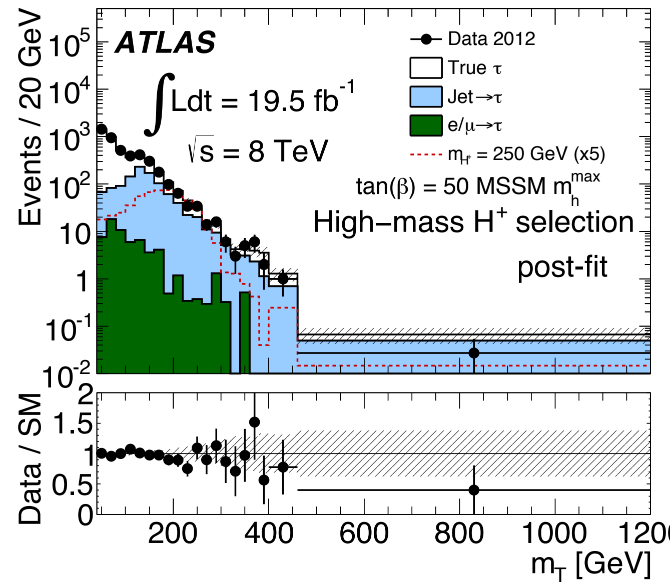


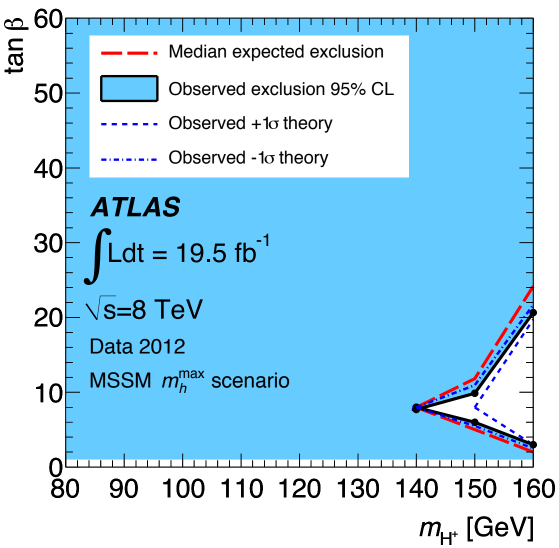
- Decay of charged Higgs boson to tau state grows with tan(β), look in state with no charged leptons
- Seed event with hadronic τ (27-29 GeV) + MET (40-50 GeV) trigger
- Require 4 (3) jets for low(high) signal selection, at least one b-tag, single high p_T hadronic τ, large MET and MET significance
- Data embedding used to model events with real τ
- Multi-jet backgrounds estimate with matrix method, with fake and real probabilities parameterized in p_T, eta and ntrack
  - Fit multi-jet background to functional form to estimate high-m_T tail

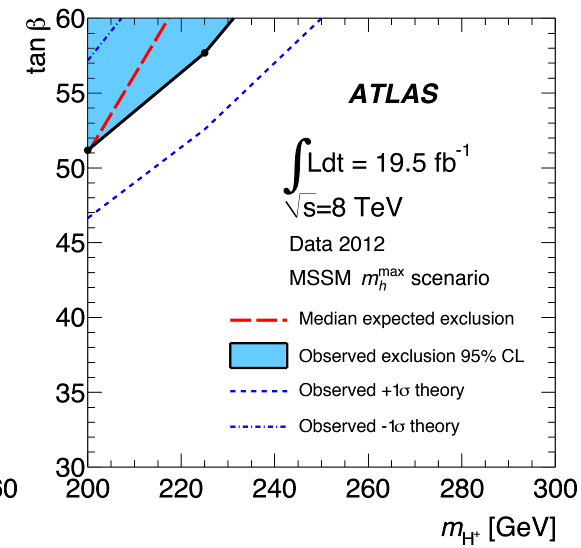


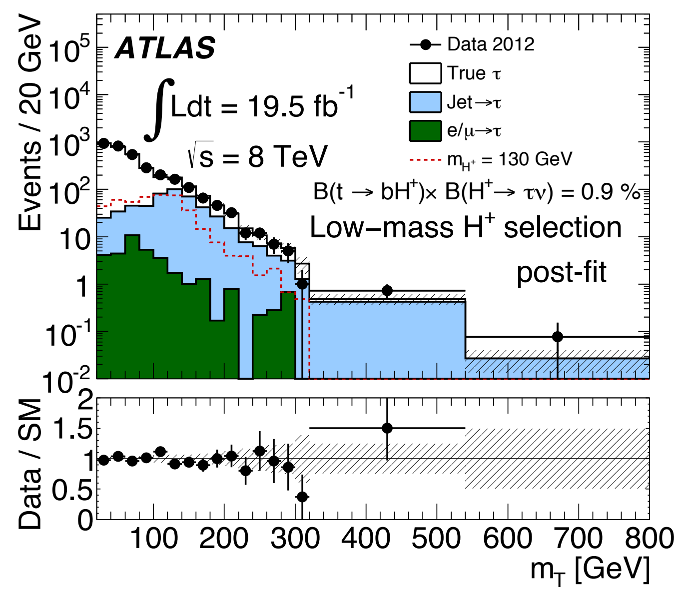


- m_T is used as discriminating variable
- Set separate low-mass and high-mass limits
- Interpret in the context of various MSSM scenarios, but also set generic limits

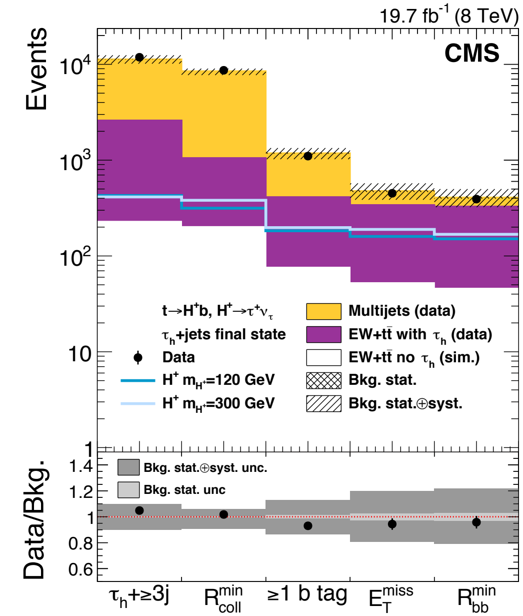


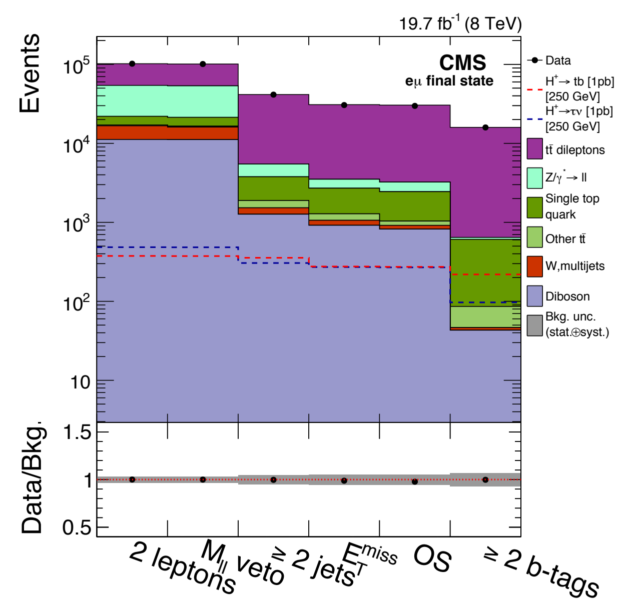




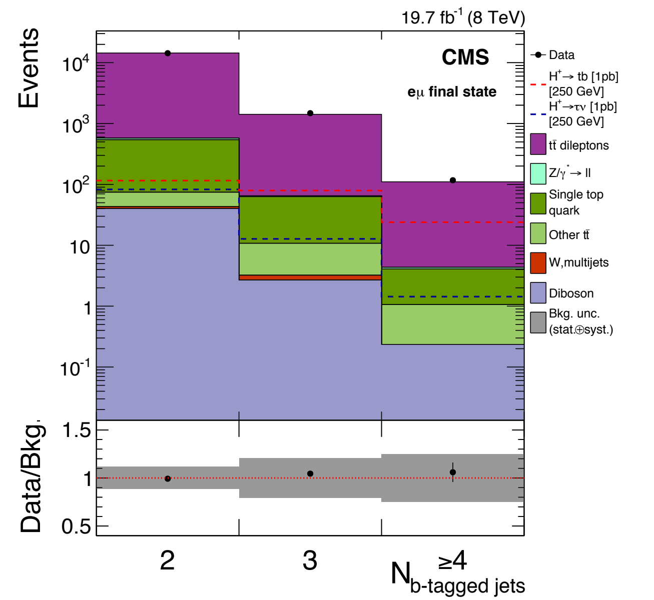


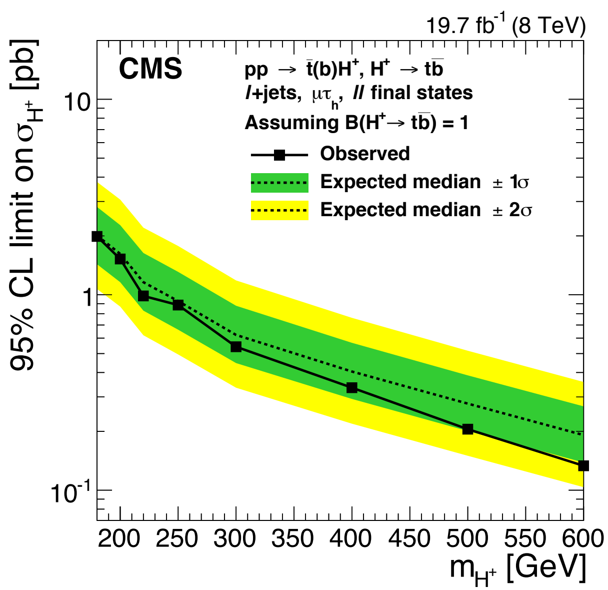
- Search for low-mass $H^+ \to \tau\nu$ in all-jets channel (low and high mass), $H^+ \to \tau\nu$ in $\mu\tau_h$ and ll(high mass) and $H^+ \to tb$ in $\mu\tau_h$, ll and single lepton channels
- Events seeded by hadronic τ (35 GeV)+ MET (70GeV) trigger, muon or dilepton triggers
- Data embedding used to model events with real τ in all-jets state
- Multi-jet backgrounds estimated by applying mis-ID rate to loose objects
- Most other backgrounds from simulation
- Single lepton $H^+ \to tb$: divide events based on number of jets, btags and lepton flavor to control and fit backgrounds

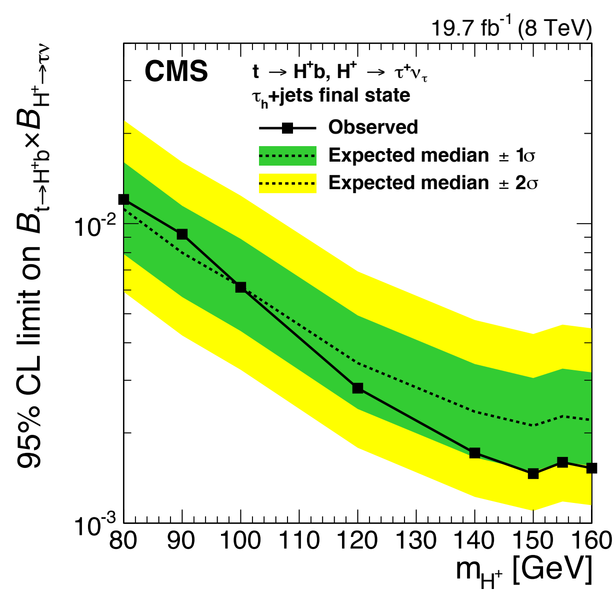


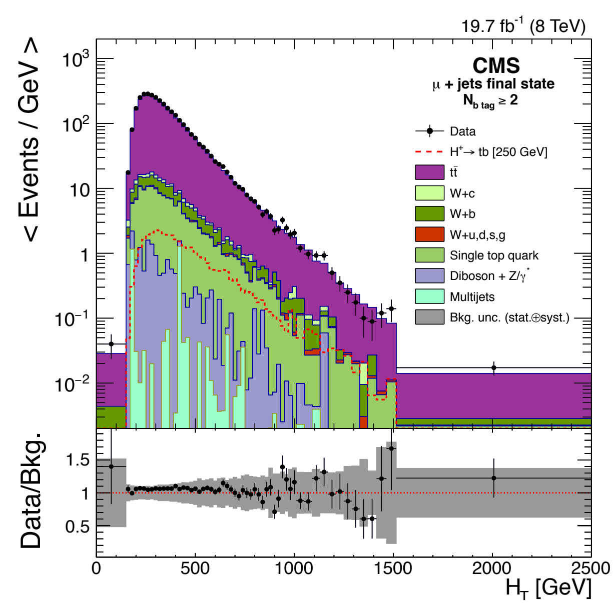


- $H^+ \to \tau\nu$ all-jets: m_T the observable
- $H^+ \to \tau\nu$/tb in ll/$\mu\tau_h$: use n-btags
- $H^+ \to$ tb in single lepton: use H_T distribution
- Need to assume model-dependent branching ratio, assume it is BR($H^+ \to \tau\nu$) = 1 (all-jets) and BR($H^+ \to$ tb) = 1 (otherwise)
- Can combine analyses to set limits on variety of MSSM space

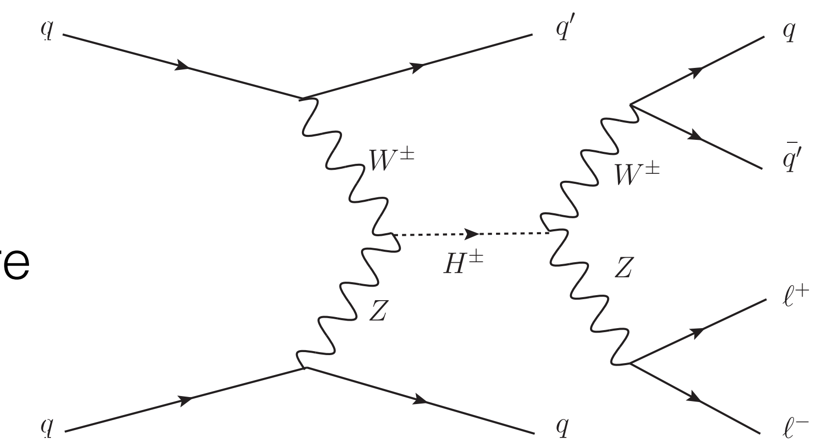


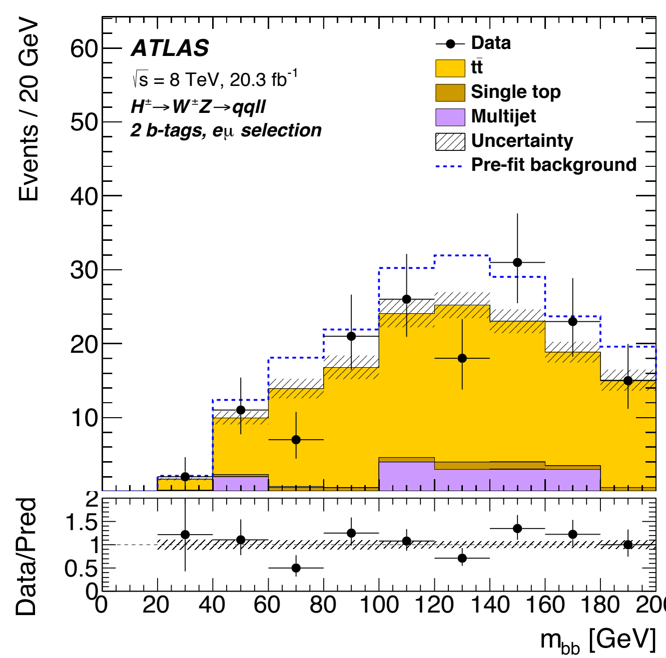






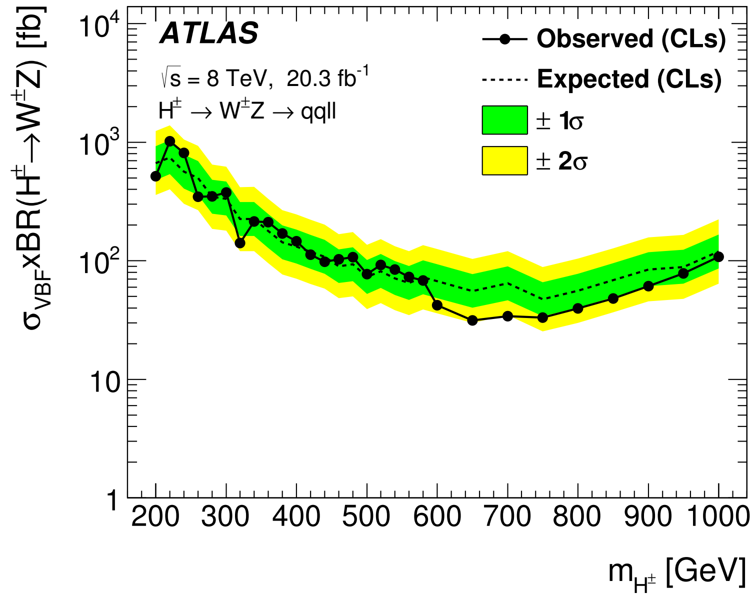
- Higgs triplet model: Add additional triplets (not doublet) to SM Higgs sector
- Trigger with single- and di-lepton e and μ triggers
- Select Z→ll and W→qq decays, then require two forward jets separated in η with large dijet mass
- Form m_{llqq} but first constrain m_{qq} to m_W
- Require large Z boson p_T and small angle between charge leptons
- Multijet: Fit dilepton mass to templates formed with inverted electron isolation (negligible in muons)
- Reject ttbar by requiring less than 2 btags and low MET significance, eμ events with 2 btags used to normalize remainder
- Z+jets normalization left free to float in the fit (dominates)

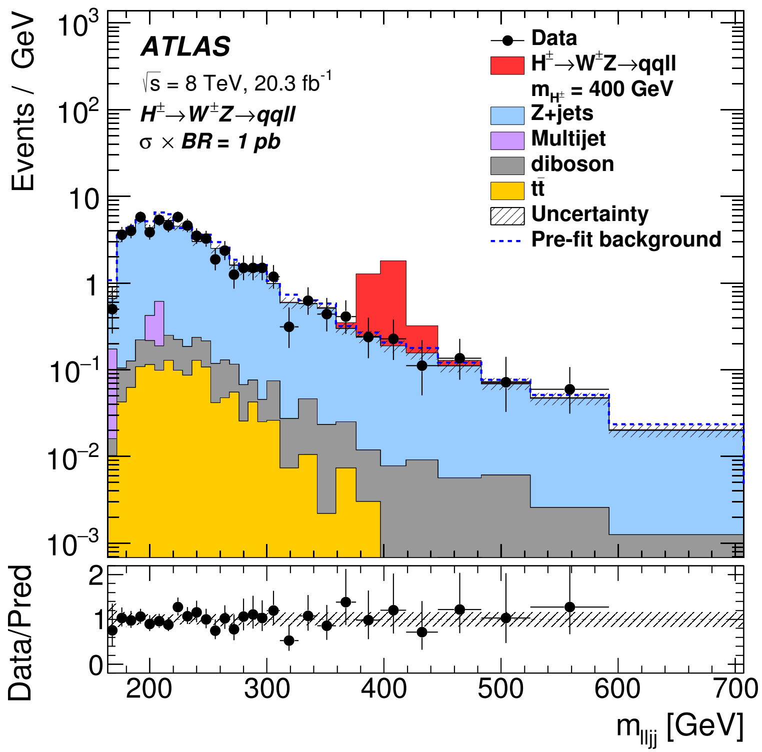


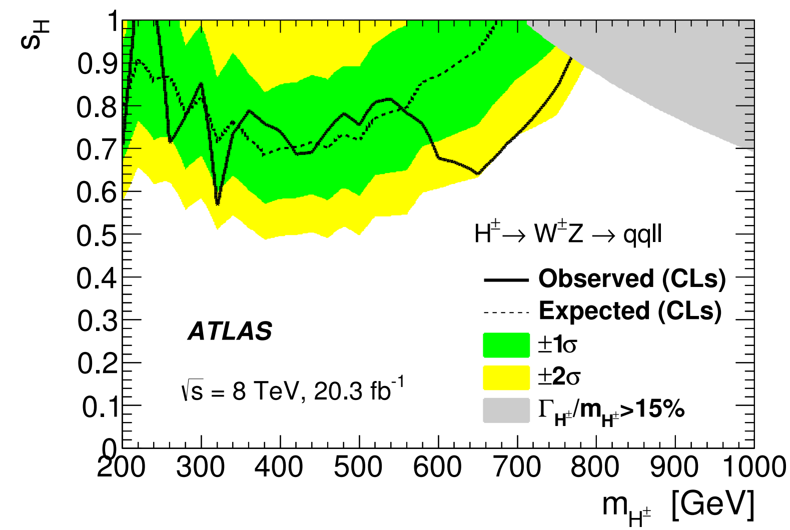


ATLAS search for $H^+ \to W^+Z$ in VBF

- Set limits as a function of charged Higgs boson mass
- $(s_H)^2$ is the fraction of vector boson mass squared generated by triplet vev (free parameter)

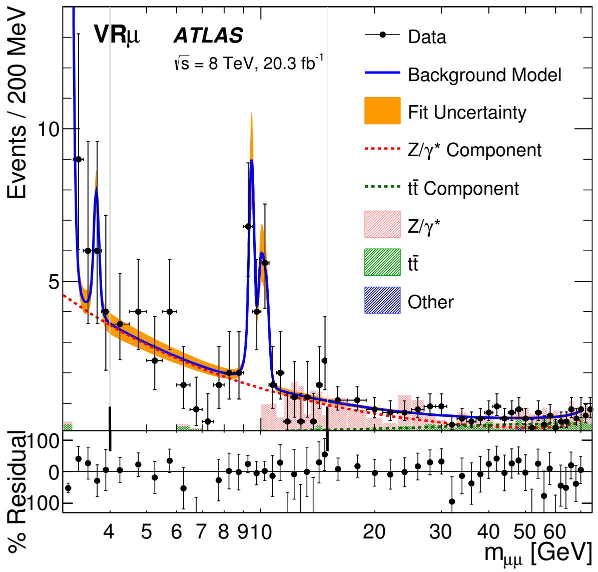


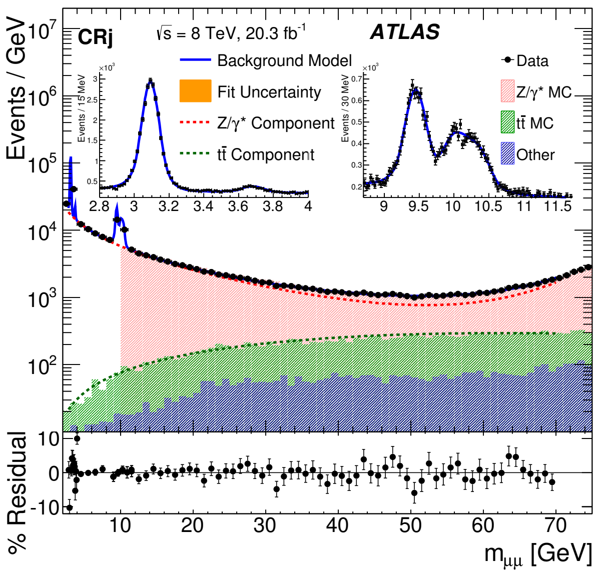




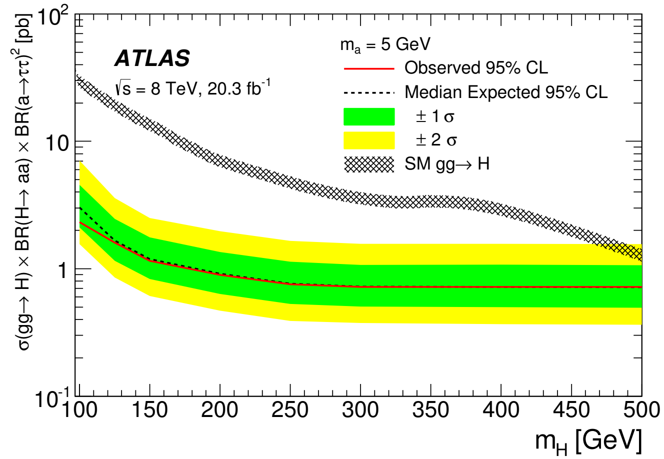
- In many models (NMSSM, hidden sector models), 125 GeV h can decay to lighter scalars (a), which then decays to light object ($\mu\mu$,$\tau\tau$,$\gamma\gamma$)
- Very different backgrounds than standard Higgs analyses
- Reduced rate by asking for decays to muons or photons, to improve mass resolution

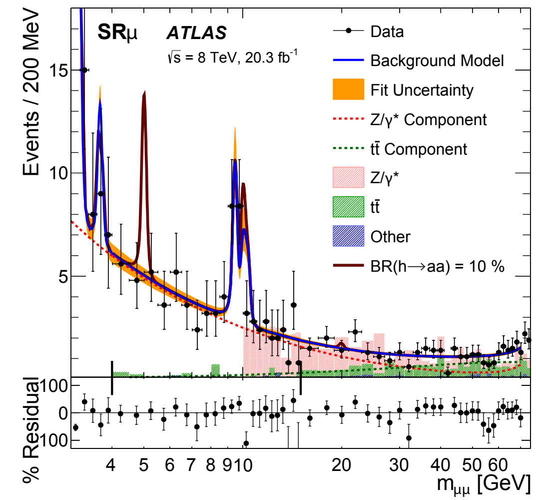
- Seeded by single and dimuon triggers
- Look for one tau to decay hadronically, the other to electron or muon back-to-back with dimuon candidate and potentially overlapping with τ_h
- Other lepton and leading track in nearby cone required to have opposite sign
- Control region for light flavor: == 1 jet and 0 b-tagged jets (DY, low-mass resonances)
- Control region for heavy flavor: at least two b-tagged jets (ttbar)
- Background pieces: J/Ψ and ϒ, ttbar and continuum, estimated in signal region and control region
- Check background model in validation regions with same sign

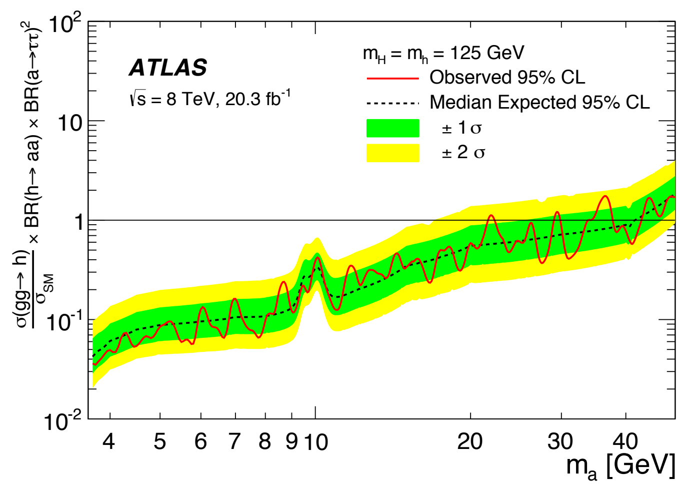


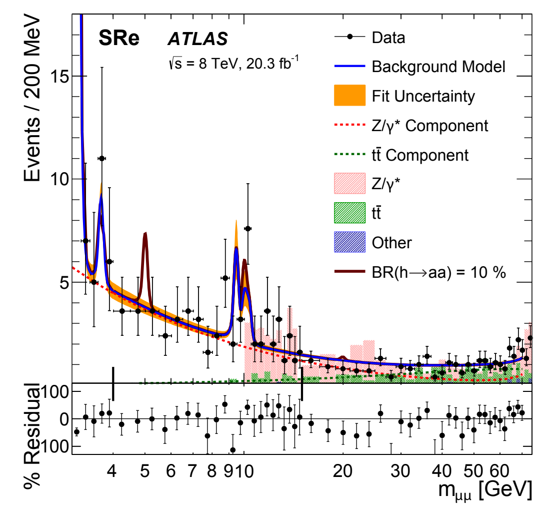


- Use dimuon mass to look for signal
- Scan and set limits as a function of m_a
- Set limits for low-mass resonances (where analysis is optimized) and higher mass region as well

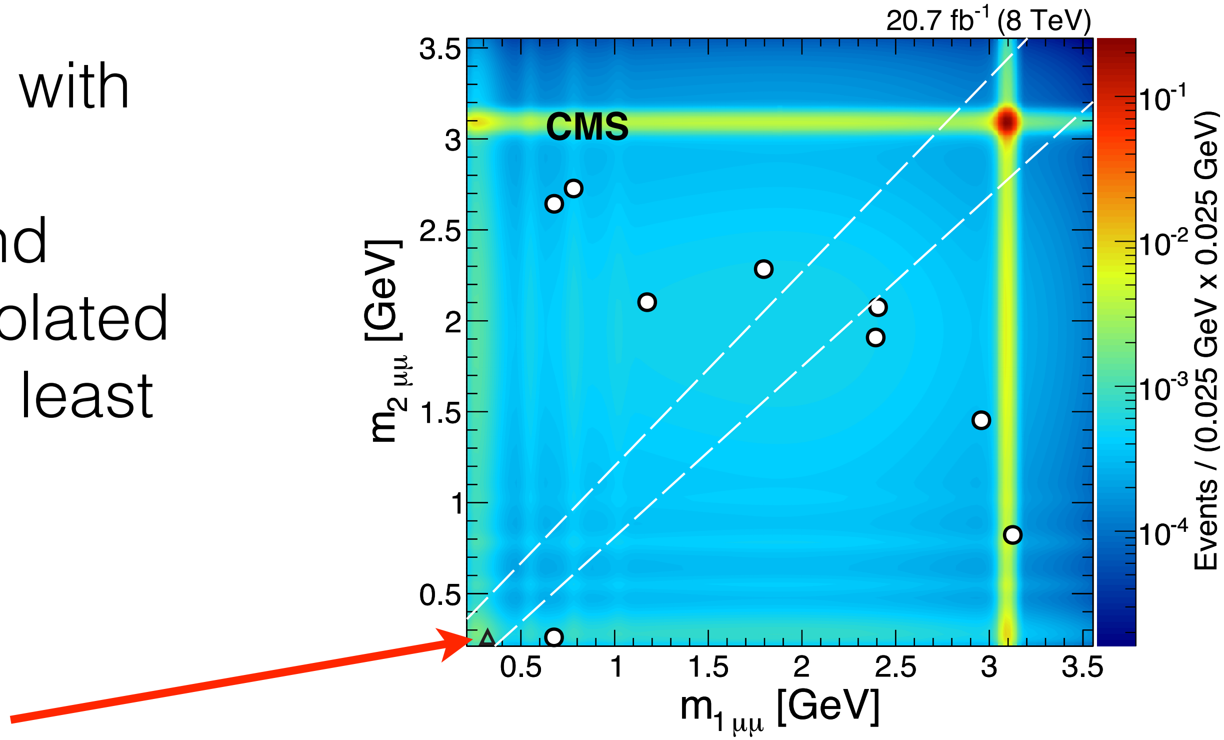




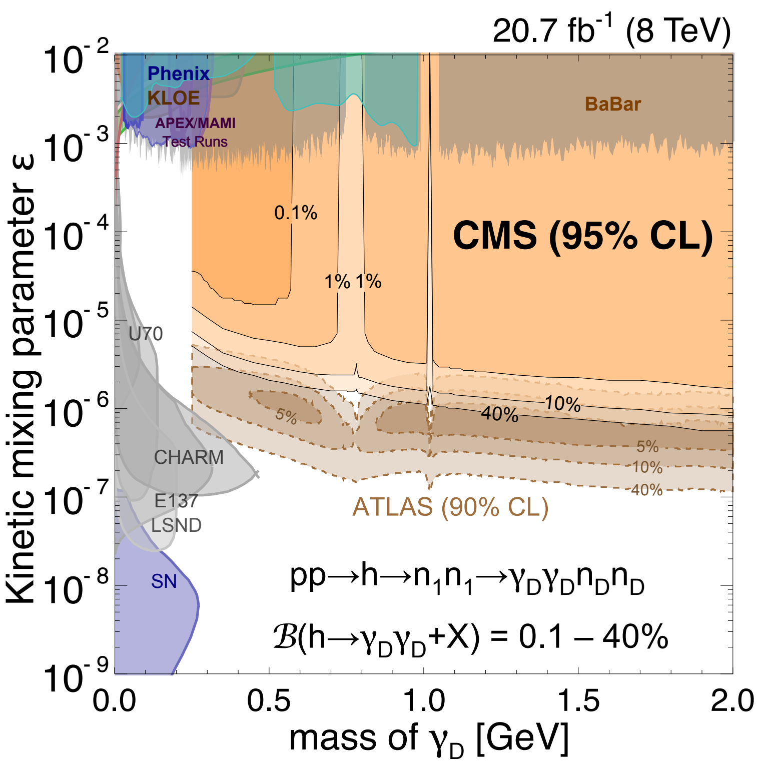


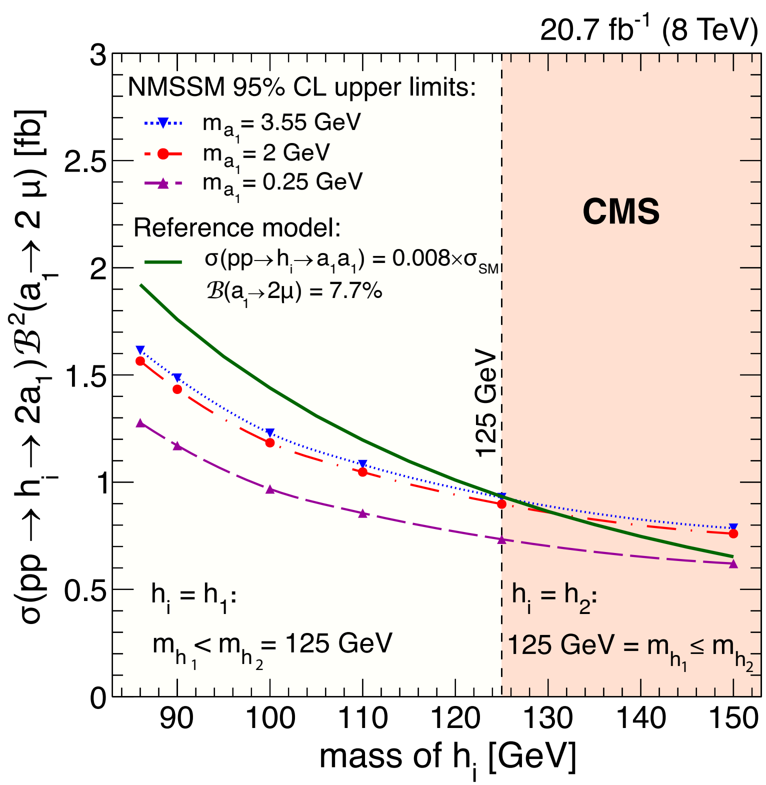


- Seeded by dimuon triggers, require 4 muon candidates offline
- Muons in a pair must have small invariant mass and either come from same vertex or have dR<0.01
- Require dimuon masses to be compatible
- Events with one dimuon pair plus third muon used to model backgrounds, normalization from events where dimuon masses not compatible
- Validate backgrounds with non-isolated muons
- Small J/Psi background estimated from non-isolated 4-muon events with at least one J/Psi candidates

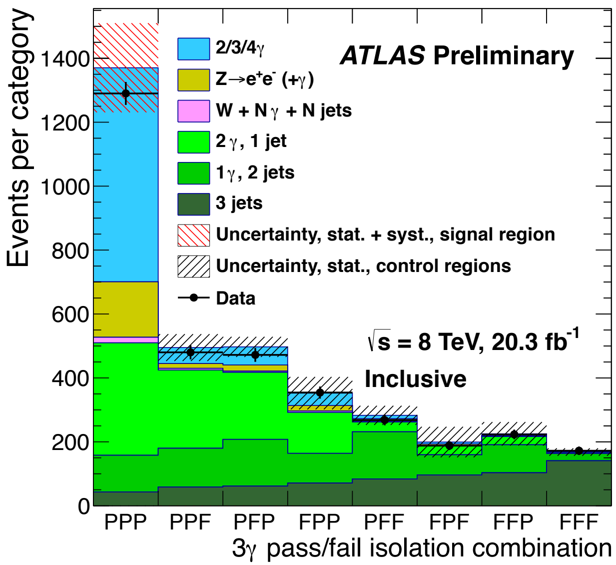


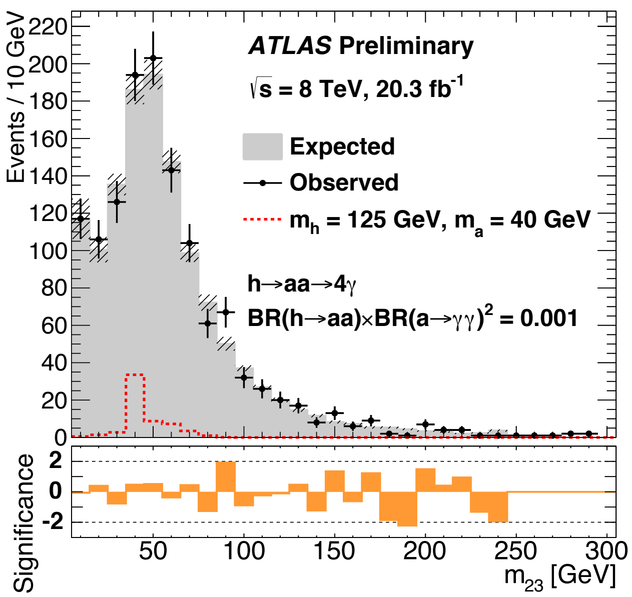
- 2.2 ± 0.7 events predicted, 1 event observed
- Set limits on various NMSSM models and on hidden sector models with kinetic mixing between dark photon and SM photon



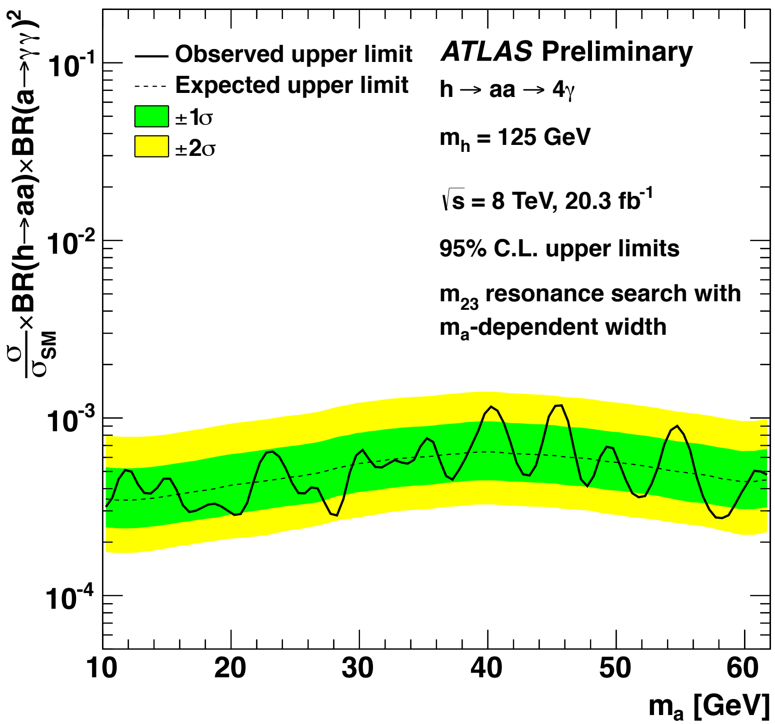


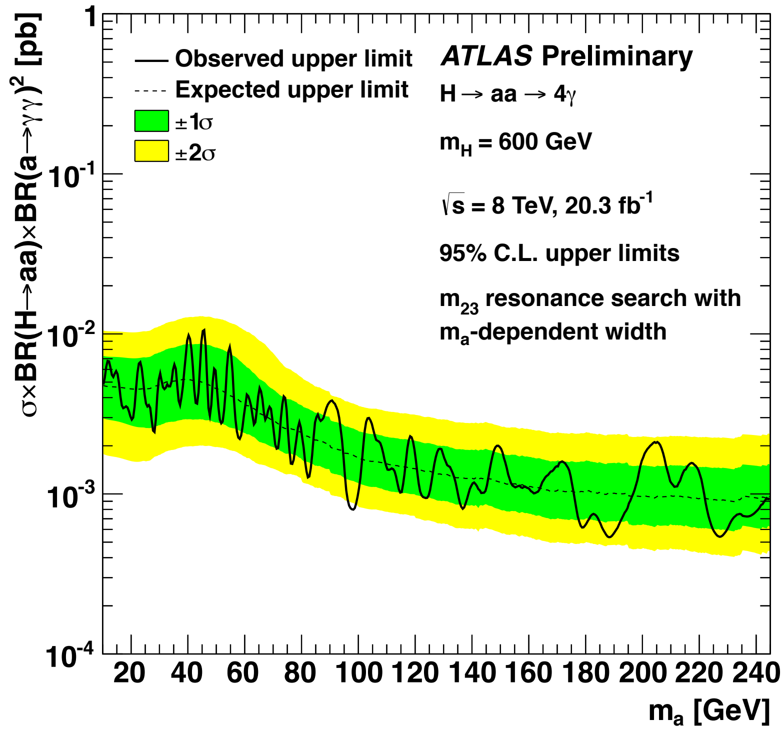
- Look for 3 isolated photons final state
- Backgrounds with real photons and photons from electrons estimated from simulation
- Data-driven estimate of rate for jets to fake photons from isolation sidebands, final estimate from likelihood matrix method based on photon isolation, p_T and **η**
- Fit all 3 distributions of diphoton masses, final limits from fits to second and third photons





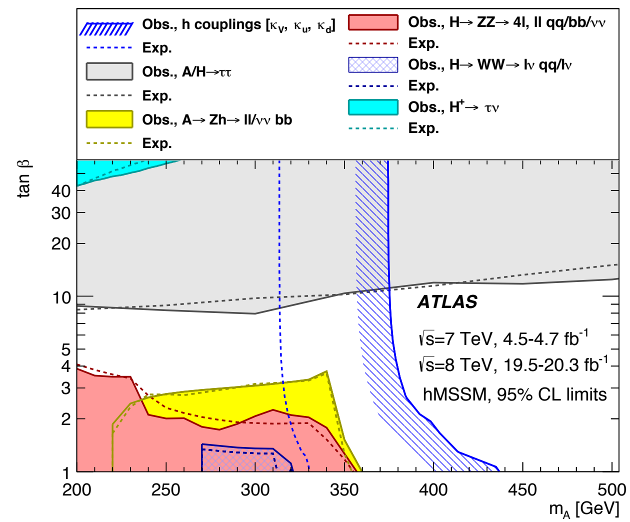
Separate limits for 125 GeV and 600 GeV resonances



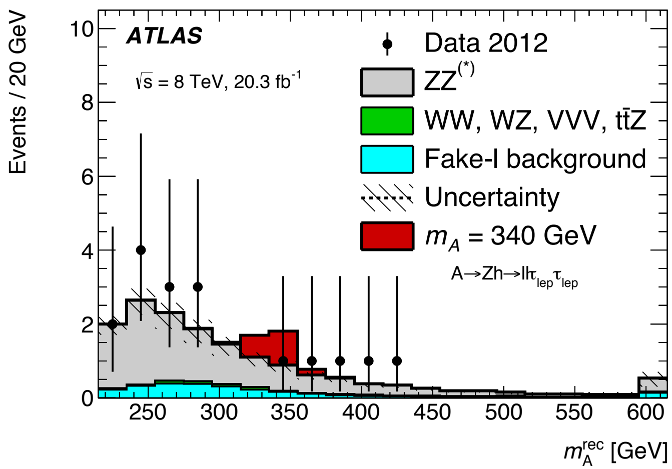


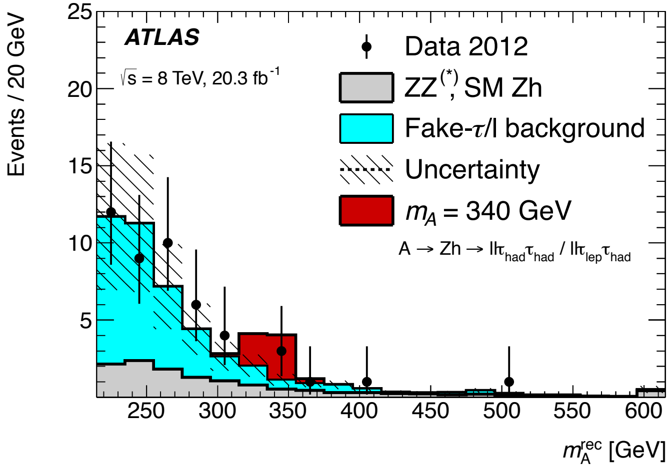
1509.00672

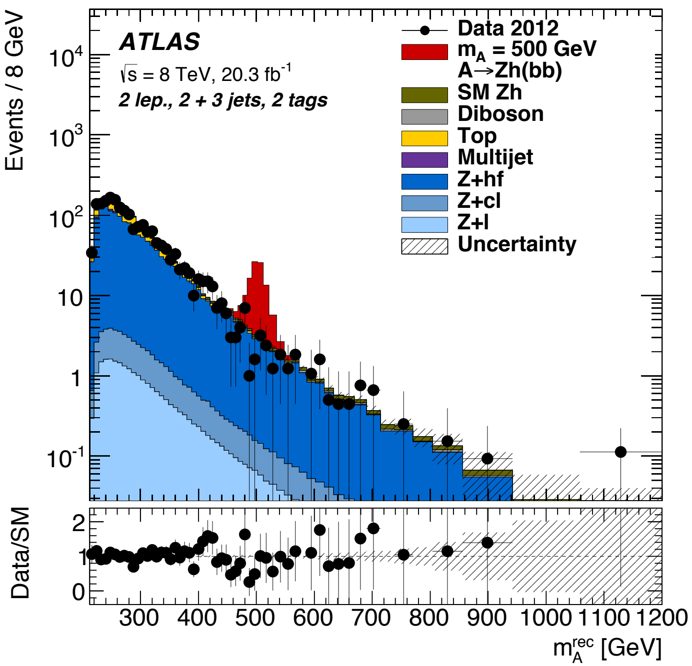
- Haven't seen strong evidence of HBSM just yet, but Run 2 is ramping up
- Good reasons to expect that new physics is hiding just around the corner
- Time to keep probing and pushing and testing the Standard Model until it breaks



BACKUP


ATLAS
√s = 8 TeV, 20.3 fb-1
Data 2012
ZZ(*)
WW, WZ, VVV, tt̄Z
Fake-l background
Uncertainty
mA = 340 GeV
A→Zh→llτlepτlep
Events / 20 GeV
mArec [GeV]


ATLAS
√s = 8 TeV, 20.3 fb-1
Data 2012
ZZ(*), SM Zh
Fake-τ/l background
Uncertainty
mA = 340 GeV
A → Zh → llτhadτhad / llτlepτhad
Events / 20 GeV
mArec [GeV]


ATLAS
√s = 8 TeV, 20.3 fb-1
2 lep., 2 + 3 jets, 2 tags
Data 2012
mA = 500 GeV
A→Zh(bb)
SM Zh
Diboson
Top
Multijet
Z+hf
Z+cl
Z+l
Uncertainty
Events / 8 GeV
Data/SM
mArec [GeV]

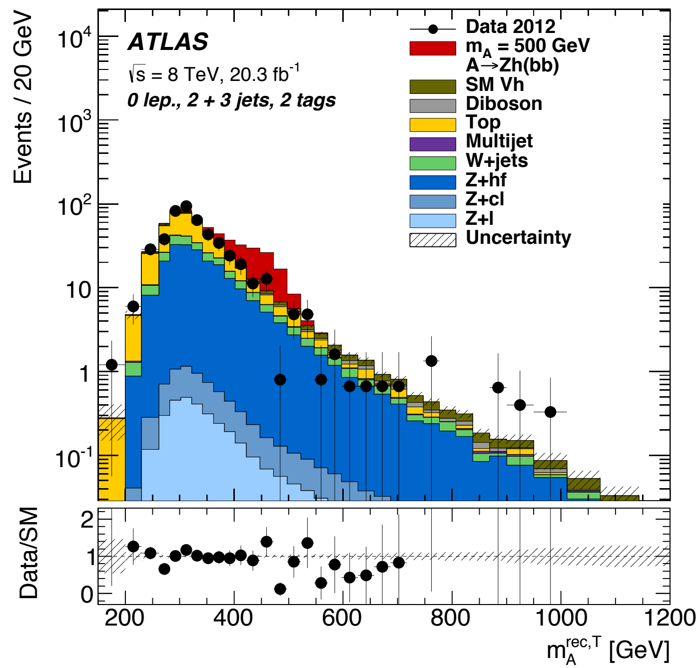

ATLAS
√s = 8 TeV, 20.3 fb-1
0 lep., 2 + 3 jets, 2 tags
Data 2012
mA = 500 GeV
A→Zh(bb)
SM Vh
Diboson
Top
Multijet
W+jets
Z+hf
Z+cl
Z+l
Uncertainty
Events / 20 GeV
Data/SM
mArec,T [GeV]

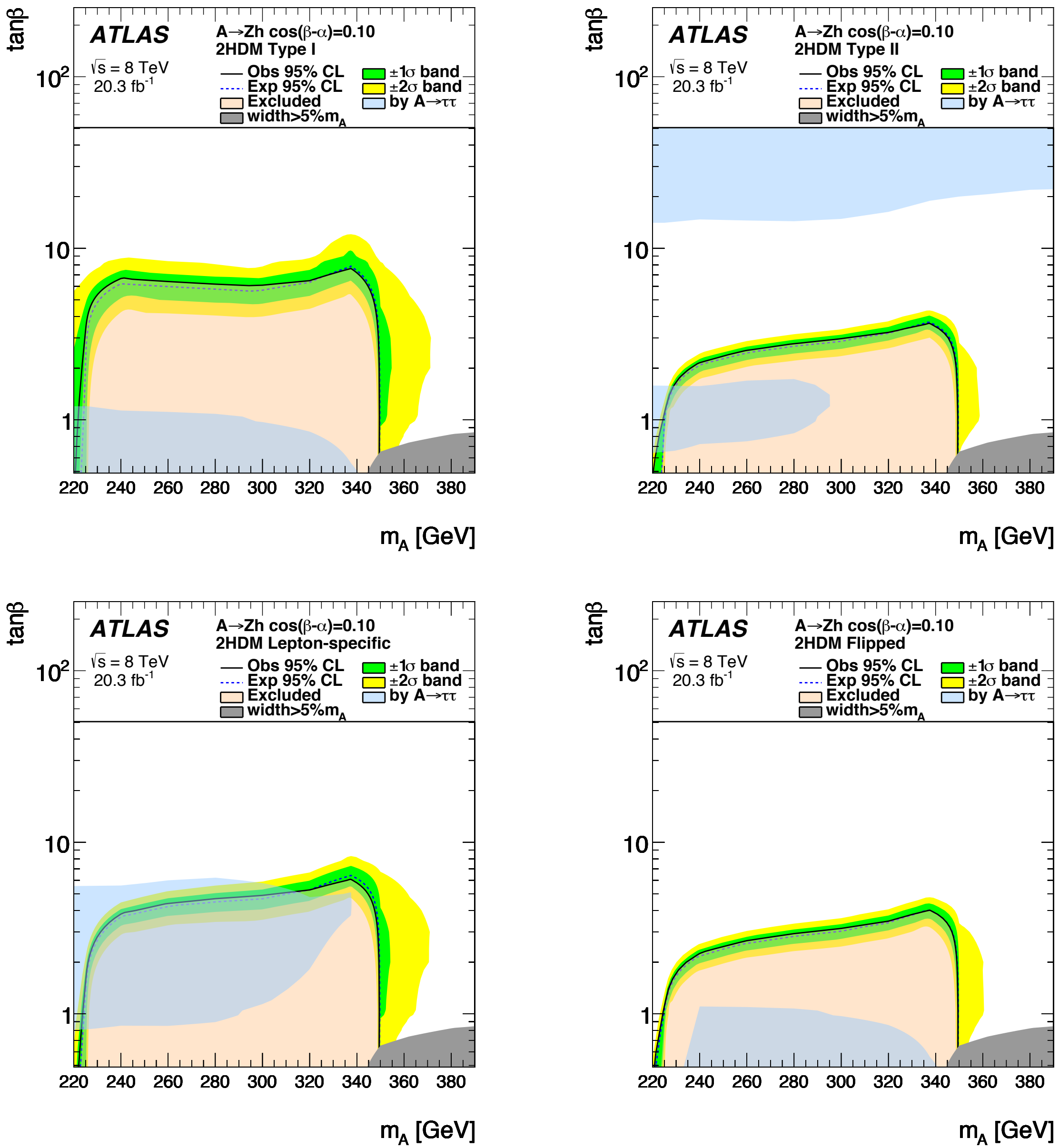
Table 2
Predicted and observed number of events for the $\ell\ell bb$ and $\nu\nu bb$ final states shown after the profile likelihood fit to the data.

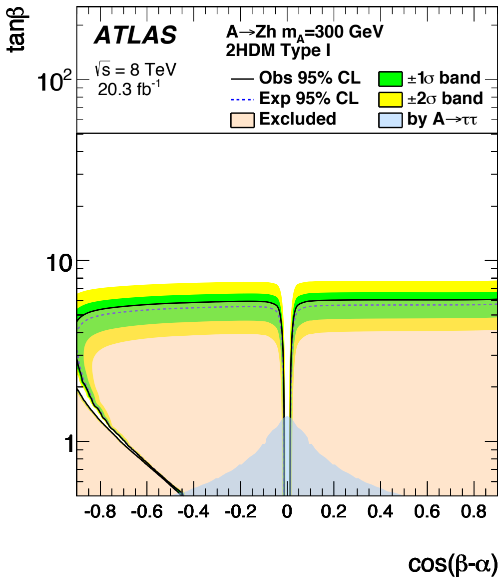
	$\ell\ell bb$	$\nu\nu bb$
Z+jets	1443 ± 60	225 ± 11
W+jets	–	55 ± 8
Top	317 ± 28	203 ± 15
Diboson	30 ± 5	10.8 ± 1.6
SM Zh, Wh	31.7 ± 1.8	22.5 ± 1.2
Multi-jet	20 ± 16	3.2 ± 3.1
Total background	1843 ± 34	521 ± 12
Data	1857	511

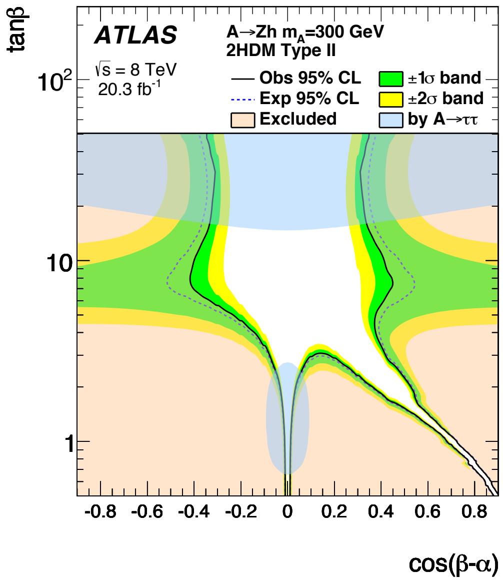
Table 1
The number of predicted and observed events for the $\ell\ell\tau\tau$ channels.

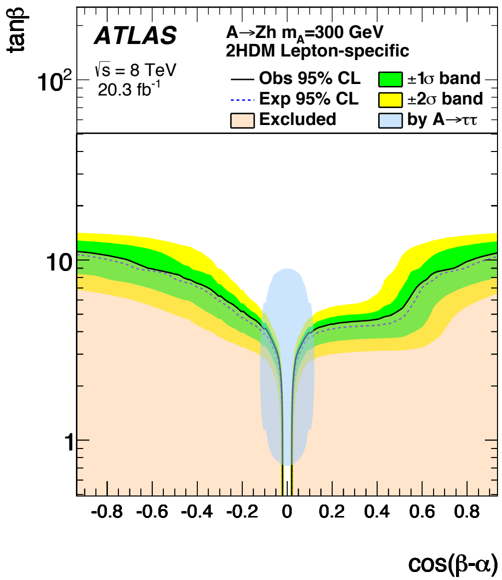
	Expected Background	Data
$\ell\ell\tau_{\mathrm{had}}\tau_{\mathrm{had}}$	28 ± 6	29
$\ell\ell\tau_{\mathrm{lep}}\tau_{\mathrm{had}}$	17 ± 4	18
$\ell\ell\tau_{\mathrm{lep}}\tau_{\mathrm{lep}}$ (SF)	9.5 ± 0.6	10
$\ell\ell\tau_{\mathrm{lep}}\tau_{\mathrm{lep}}$ (DF)	7.2 ± 0.7	7

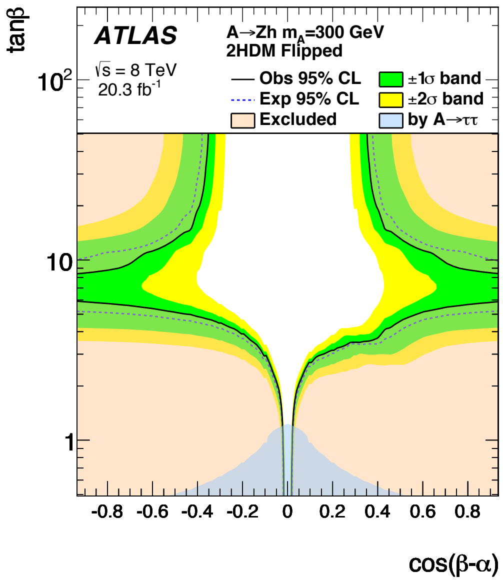
ATLAS search for A→Zh→ll/$\nu\nu$ + bb/$\tau\tau$ 1502.04478

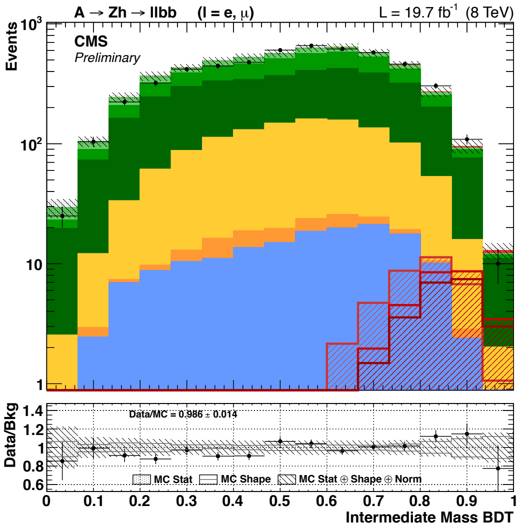



tanβ
ATLAS
A→Zh m_A=300 GeV
2HDM Type I
√s = 8 TeV
20.3 fb-1
Obs 95% CL
Exp 95% CL
Excluded
±1σ band
±2σ band
by A→ττ
cos(β-α)

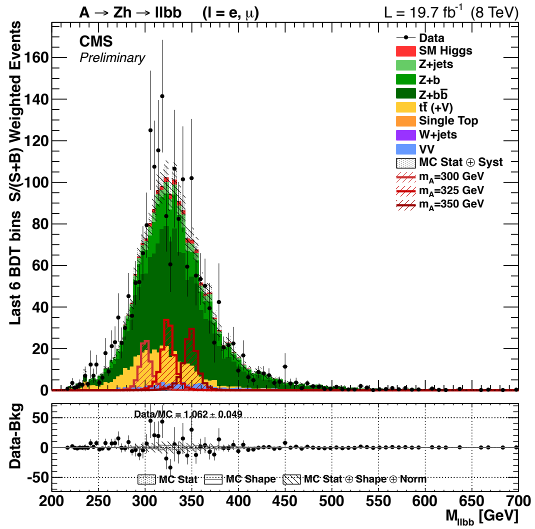

tanβ
ATLAS
A→Zh m_A=300 GeV
2HDM Type II
√s = 8 TeV
20.3 fb-1
Obs 95% CL
Exp 95% CL
Excluded
±1σ band
±2σ band
by A→ττ
cos(β-α)


tanβ
ATLAS
A→Zh m_A=300 GeV
2HDM Lepton-specific
√s = 8 TeV
20.3 fb-1
Obs 95% CL
Exp 95% CL
Excluded
±1σ band
±2σ band
by A→ττ
cos(β-α)

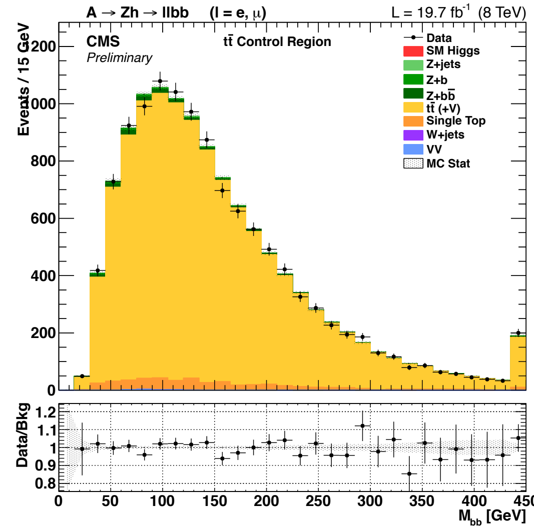

tanβ
ATLAS
A→Zh m_A=300 GeV
2HDM Flipped
√s = 8 TeV
20.3 fb-1
Obs 95% CL
Exp 95% CL
Excluded
±1σ band
±2σ band
by A→ττ
cos(β-α)



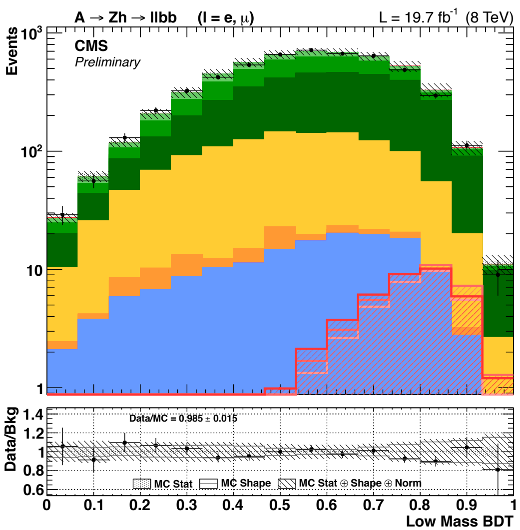
A → Zh → llbb (l = e, μ)
L = 19.7 fb⁻¹ (8 TeV)
CMS
Preliminary
Events
Data/Bkg
Data/MC = 0.986 ± 0.014
MC Stat
MC Shape
MC Stat ⊕ Shape ⊕ Norm
Intermediate Mass BDT



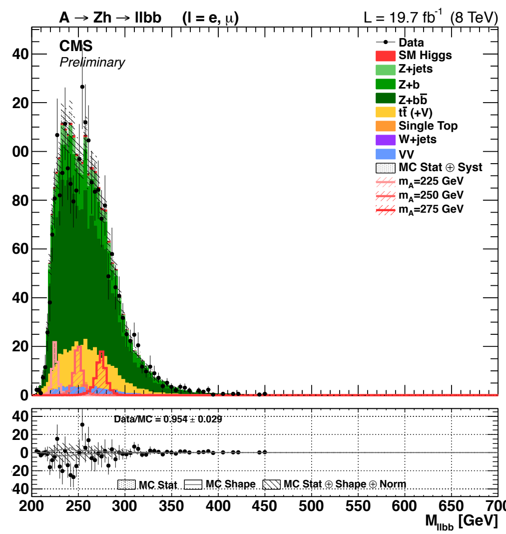
A → Zh → llbb (l = e, μ)
L = 19.7 fb⁻¹ (8 TeV)
CMS
Preliminary
Last 6 BDT bins S/(S+B) Weighted Events
Data
SM Higgs
Z+jets
Z+b
Z+bb̄
tt̄ (+V)
Single Top
W+jets
VV
MC Stat ⊕ Syst
mA=300 GeV
mA=325 GeV
mA=350 GeV
Data-Bkg
Data/MC = 1.062 ± 0.049
MC Stat
MC Shape
MC Stat ⊕ Shape ⊕ Norm
Mllbb [GeV]



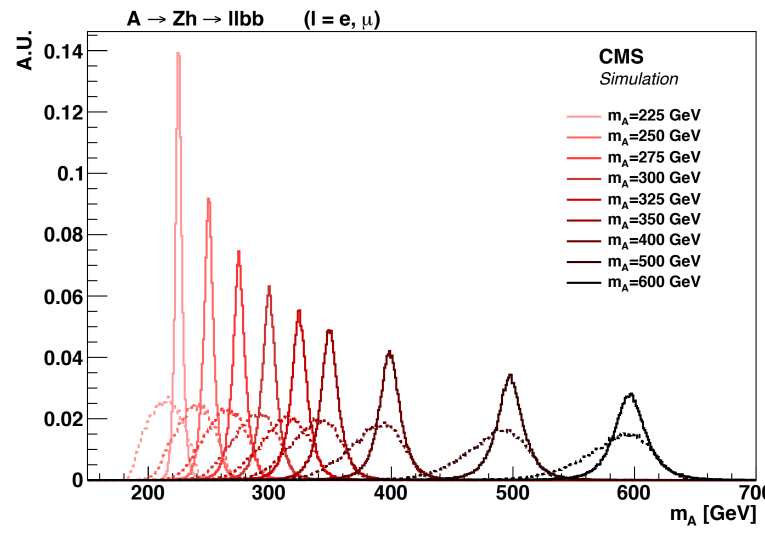
A → Zh → llbb (l = e, μ)
L = 19.7 fb⁻¹ (8 TeV)
CMS
Preliminary
tt̄ Control Region
Events / 15 GeV
Data
SM Higgs
Z+jets
Z+b
Z+bb̄
tt̄ (+V)
Single Top
W+jets
VV
MC Stat
Data/Bkg
Mbb [GeV]



A → Zh → llbb (l = e, μ)
L = 19.7 fb⁻¹ (8 TeV)
CMS
Preliminary
Events
Data/Bkg
Data/MC = 0.985 ± 0.015
MC Stat
MC Shape
MC Stat ⊕ Shape ⊕ Norm
Low Mass BDT



A → Zh → llbb (l = e, μ)
L = 19.7 fb⁻¹ (8 TeV)
CMS
Preliminary
Data
SM Higgs
Z+jets
Z+b
Z+bb̄
tt̄ (+V)
Single Top
W+jets
VV
MC Stat ⊕ Syst
mA=225 GeV
mA=250 GeV
mA=275 GeV
Data/MC = 0.954 ± 0.029
MC Stat
MC Shape
MC Stat ⊕ Shape ⊕ Norm
Mllbb [GeV]

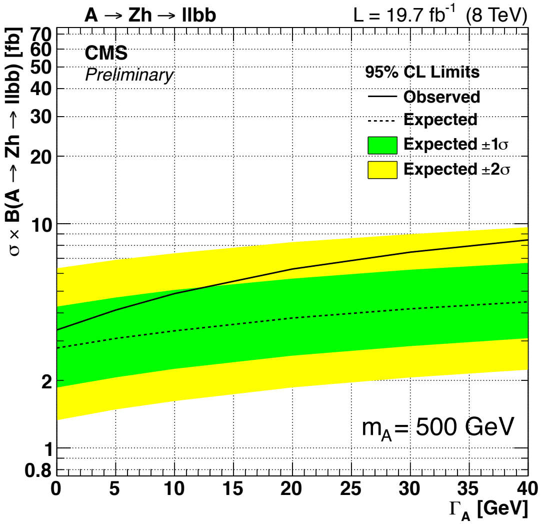


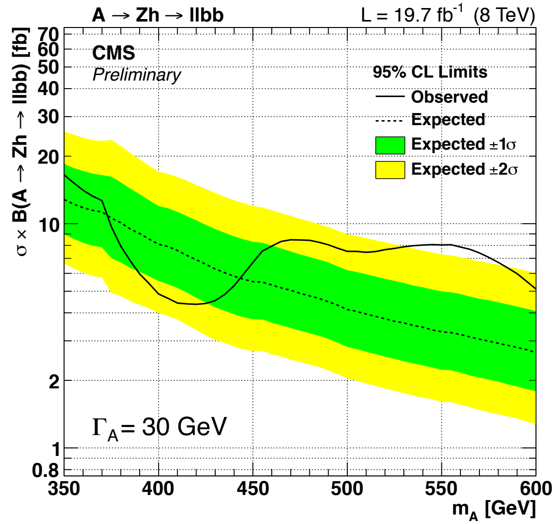
A → Zh → llbb (l = e, μ)
CMS
Simulation
A.U.
mA=225 GeV
mA=250 GeV
mA=275 GeV
mA=300 GeV
mA=325 GeV
mA=350 GeV
mA=400 GeV
mA=500 GeV
mA=600 GeV
mA [GeV]

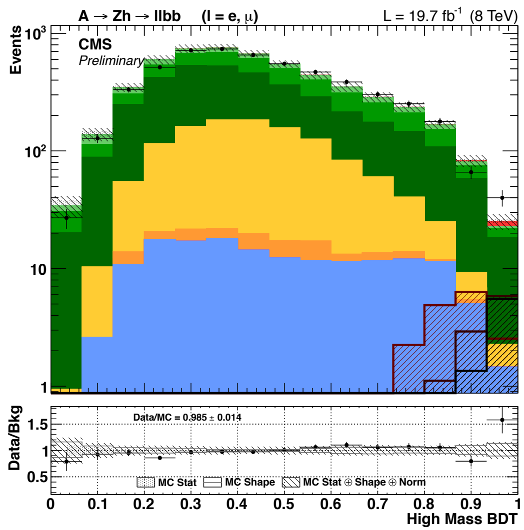
CMS search for A→Zh→ll + bb/ττ

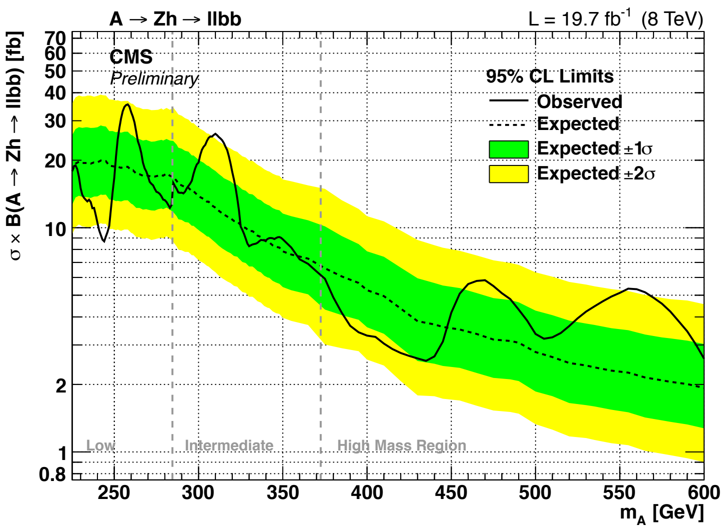
1504.04710/HIG-15-001

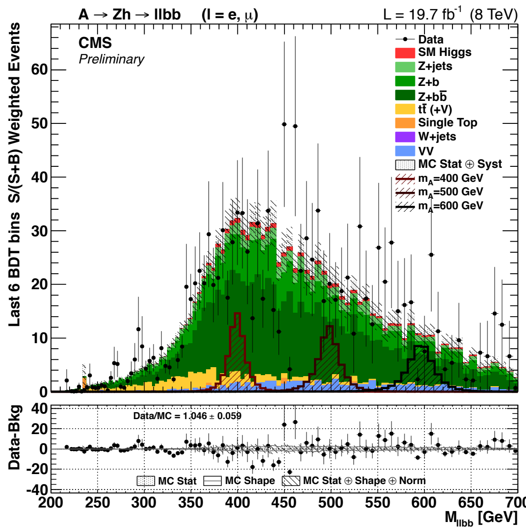
Northern Illinois University











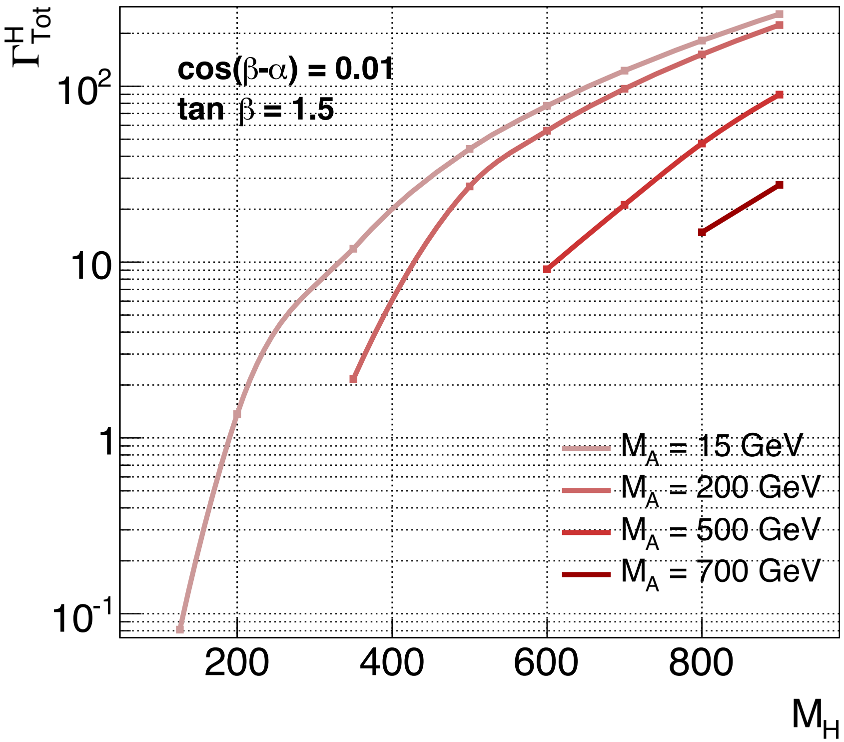


Table 3: Summary of systematic uncertainties for backgrounds and signals. The top table shows uncertainties concerning shape, bottom normalization. The last column reports the increase in the expected limit when each single systematic source is frozen.

	Main backgrounds (Drell-Yan, $t\bar{t}$)	Other electroweak (single-top, VV, Vh)	Signal	Effect on exp. limit after freezing
Shape				
Jet Energy Scale	0 – 4%		0 – 8%	0 – 1%
Jet Energy Resolution	0 – 2%		0 – 4%	0 – 1%
b-tagging	0 – 4%		0 – 8%	< 1%
Factorization and renormalization scale	0 – 6%		6 – 10%	0 – 2%
Monte Carlo modeling	0 – 15%		-	0 – 6%
Monte Carlo statistics	1 – 4%		-	0 – 4%
Normalization				
Control region fit	0 – 2.4%	-	-	< 1%
Extrapolation	2 – 13%	-	-	0 – 1%
Lepton and trigger efficiency	-	2.5%	2.5%	< 1%
Jet Energy Scale	-	5.7%	3.8 – 0.2%	< 1%
Jet Energy Resolution	-	3.2%	0.8 – 0.5%	< 1%
b-tagging	-	4.9%	3.6 – 3.2%	< 1%
Unclustered E_T^{miss}	-	1.9%	1.4 – 1.0%	< 1%
Pile-up	-	0.9%	1.2%	< 1%
PDF	-	4.3%	4.0 – 7.9%	< 1%
Cross Section	-	9.2 – 15 %	-	< 1%
Luminosity	-	2.6%	2.6%	< 1%

Table 2: List and description of all the variables included in the BDTs.

Variable	Description
CSV_1	highest CSV value between the two jets
CSV_2	second-highest CSV value
$m_{\ell\ell}$	invariant mass of the lepton pair
p_T^Z	p_T of the Z candidate
p_T^h	p_T of the dijet pair (h candidate)
ΔR_{bb}	angular separation of the two jets in the $\eta - \varphi$ space
τ_{bb}	twist angle between the two jets $\tau \equiv \tan^{-1} \Delta\varphi/\Delta\eta$ [30]
E_T^{miss} sign	Missing Energy Significance [31]
χ^2	χ^2 of the kinematic fit
S_T	scalar sum of the p_T of jets, leptons and E_T^{miss} in the event
nJets	number of jets with $p_T > 20$ GeV in the event
Centrality	Centrality of the four decay products in the A rest frame [30]
Aplanarity	event Aplanarity calculated with the four decay products [30]
$\cos\theta^*$	production polar angle of the A candidate in its rest frame
$\cos\theta_1$	Z decay angle w.r.t. its flight direction in the Z rest frame
Pull Angle	angle of the pull vector of the highest-p_T jet [32]

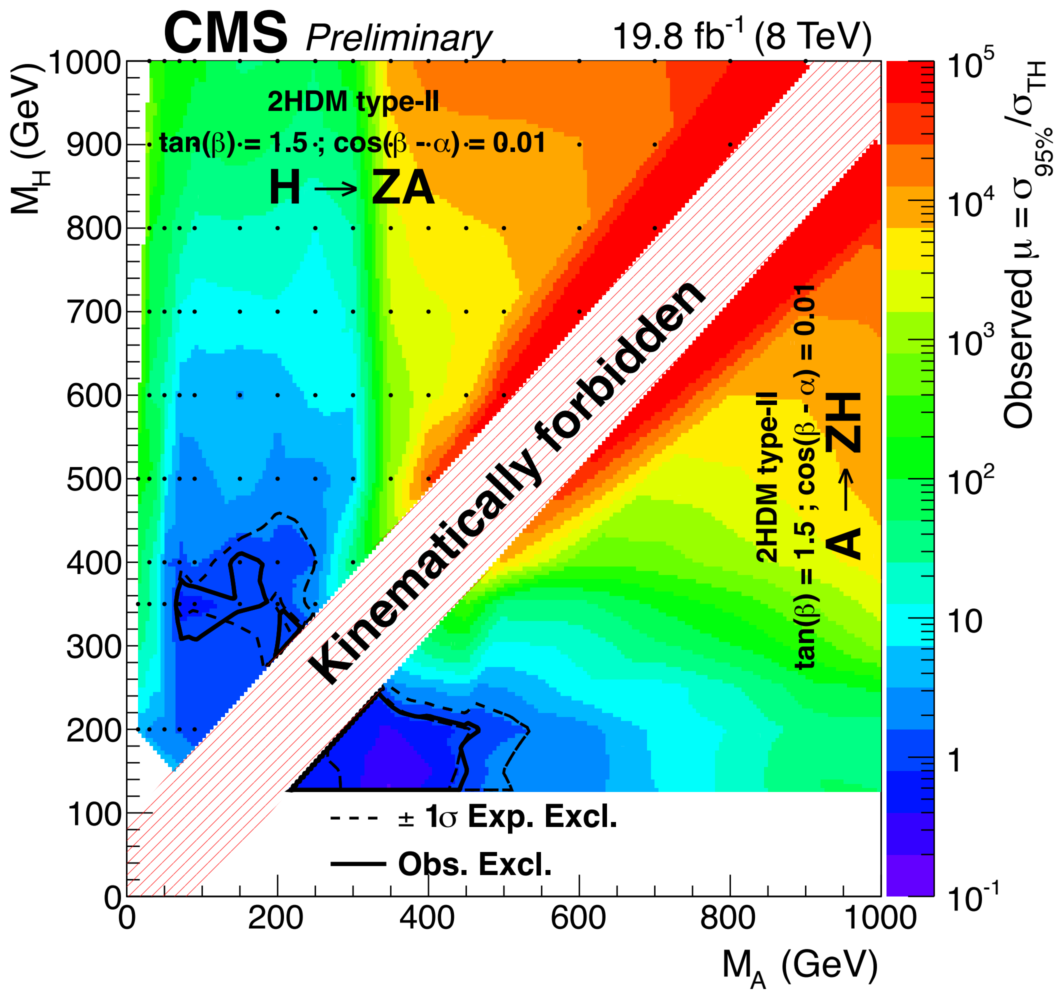
Table 1: Control regions definition (top) and scale factors (bottom) derived for the four main backgrounds. Uncertainties are statistical only.

Control Region	Z mass [GeV]	h mass [GeV]	CSV_1	CSV_2	E_T^{miss} [GeV]
Z+0 b-jets	$80 < m_{\ell\ell} < 100$	$m_{bb} < 90, m_{bb} > 140$	-	-	-
Z+1 b-jets	$80 < m_{\ell\ell} < 100$	$m_{bb} < 90, m_{bb} > 140$	Tight	not Loose	< 40
Z+2 b-jets	$80 < m_{\ell\ell} < 100$	$m_{bb} < 90, m_{bb} > 140$	Tight	Loose	< 40
Top	$m_{\ell\ell} < 80, m_{\ell\ell} > 100$	-	Tight	Loose	> 40

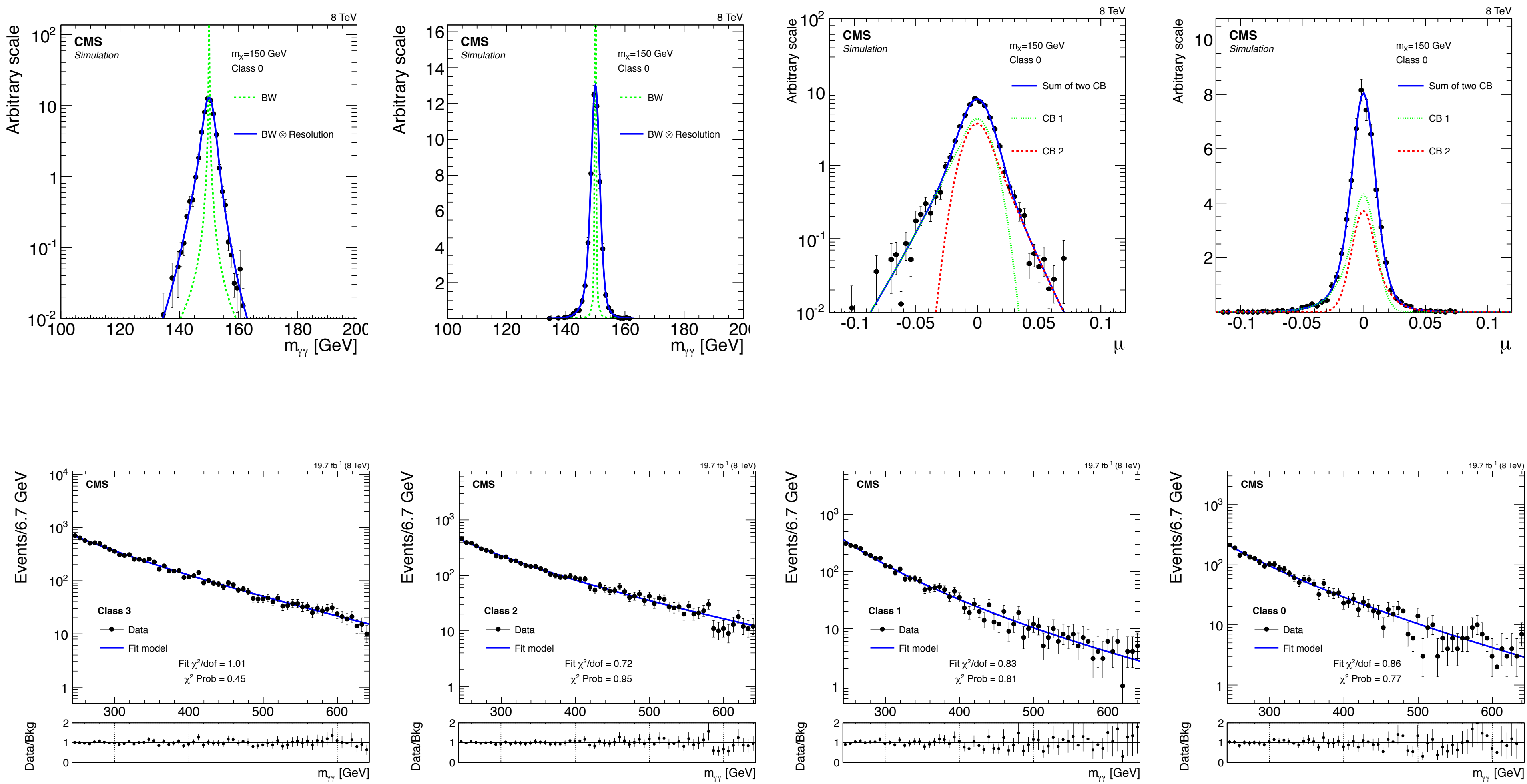
	Z+jets	Z+b	$Z + b\bar{b}$	$t\bar{t}$
Scale Factors	1.069 ± 0.002	0.945 ± 0.012	1.008 ± 0.020	0.984 ± 0.010

Table 4: Observed and expected 95% CL upper limit on $\sigma \times \mathcal{B}(A \to Zh \to \ell\ell bb)$ as a function of m_A, including all statistical and systematic uncertainties.

m_A [GeV]	225	250	275	300	325	350	400	500	600
Observed [fb]	17.9	16.8	14.8	19.5	10.1	8.84	3.29	3.35	2.61
Expected [fb]	17.9	18.1	16.4	13.6	10.0	7.84	5.27	2.79	1.93



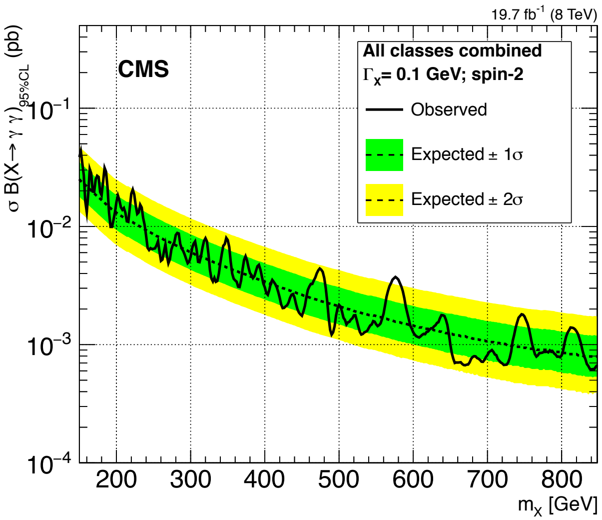
CMS Preliminary
19.8 fb-1 (8 TeV)
2HDM type-II
tan(β) = 1.5 ; cos(β - α) = 0.01
H → ZA
Kinematically forbidden
2HDM type-II
tan(β) = 1.5 ; cos(β - α) = 0.01
A → ZH
± 1σ Exp. Excl.
Obs. Excl.
M_H (GeV)
M_A (GeV)
Observed μ = σ_95%/σ_TH

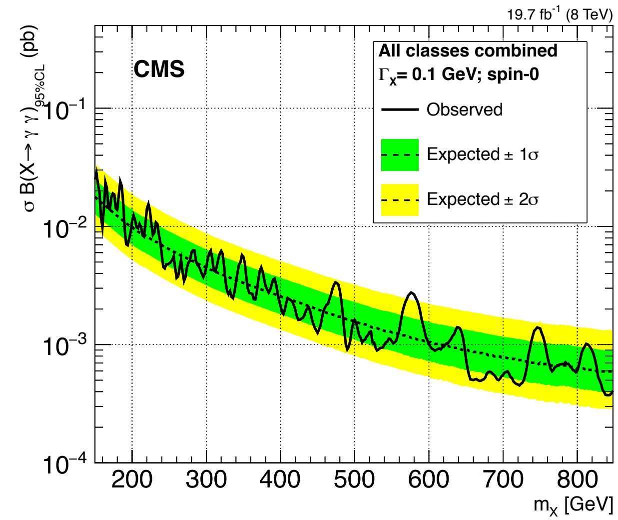


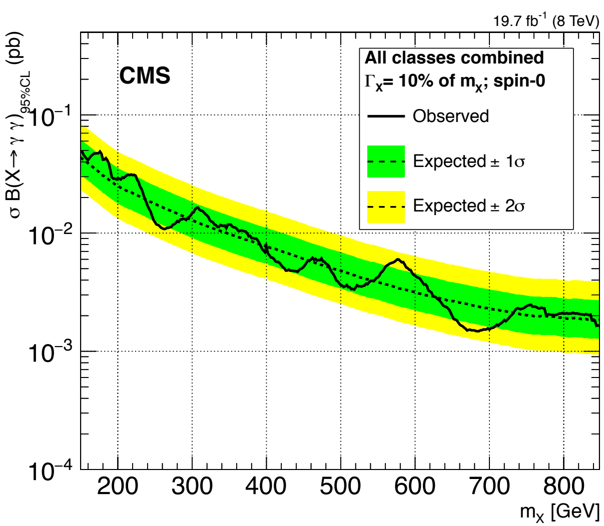
CMS
Simulation
8 TeV
m_X=150 GeV
Class 0
BW
BW ⊗ Resolution
Arbitrary scale
$m_{\gamma\gamma}$ [GeV]
Sum of two CB
CB 1
CB 2
μ
CMS
19.7 fb^{-1} (8 TeV)
Events/6.7 GeV
Class 3
Data
Fit model
Fit χ^2/dof = 1.01
χ^2 Prob = 0.45
Class 2
Fit χ^2/dof = 0.72
χ^2 Prob = 0.95
Class 1
Fit χ^2/dof = 0.83
χ^2 Prob = 0.81
Class 0
Fit χ^2/dof = 0.86
χ^2 Prob = 0.77
Data/Bkg

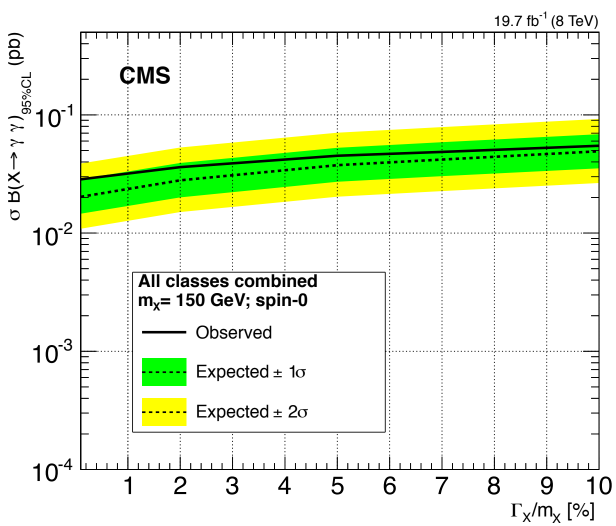
CMS search for new γγ resonances

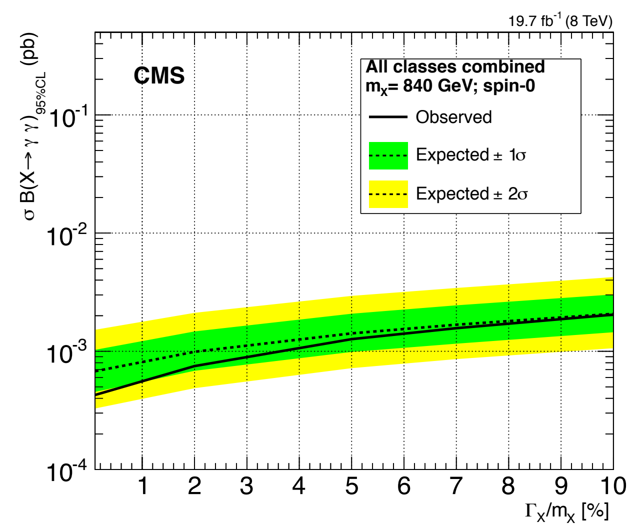
1506.02301

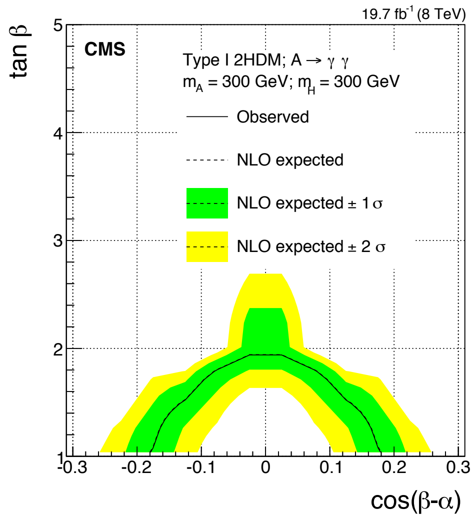


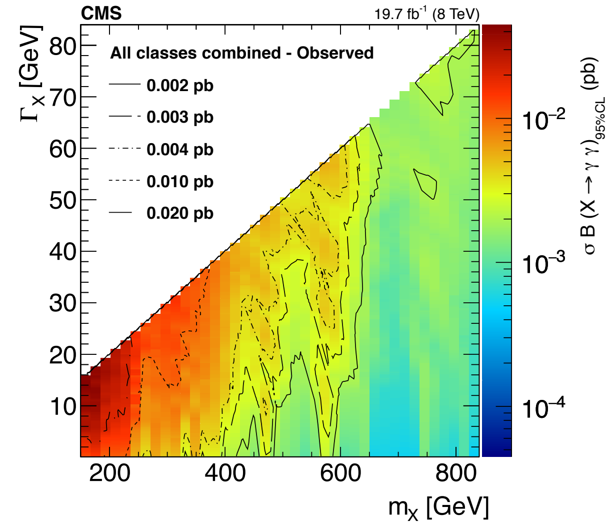


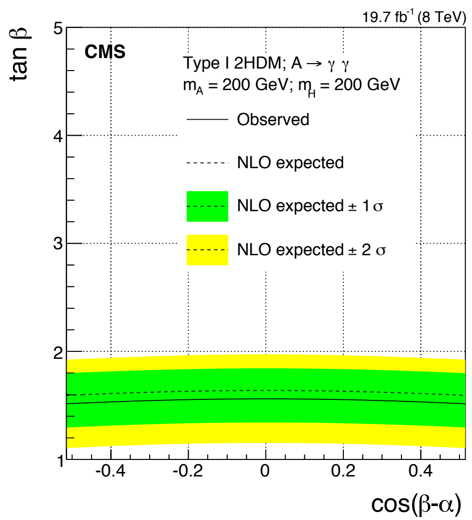


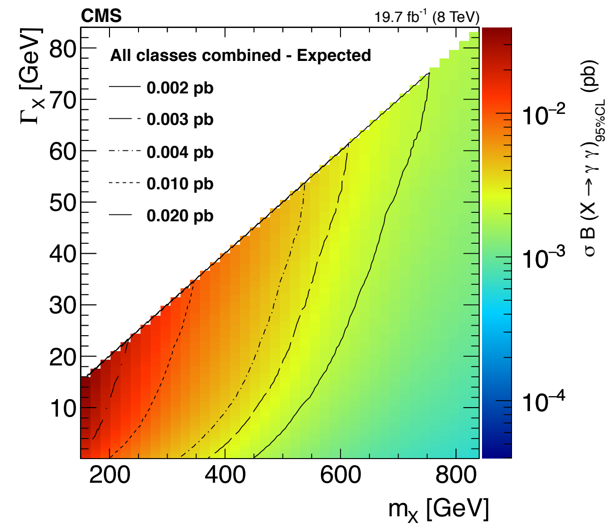





19.7 fb-1 (8 TeV)
CMS
Type I 2HDM; A → γ γ
mA = 300 GeV; mH = 300 GeV
Observed
NLO expected
NLO expected ± 1 σ
NLO expected ± 2 σ
tan β
cos(β-α)


CMS
19.7 fb-1 (8 TeV)
All classes combined - Observed
0.002 pb
0.003 pb
0.004 pb
0.010 pb
0.020 pb
ΓX [GeV]
mX [GeV]
σ B (X → γ γ)95%CL (pb)


19.7 fb-1 (8 TeV)
CMS
Type I 2HDM; A → γ γ
mA = 200 GeV; mH = 200 GeV
Observed
NLO expected
NLO expected ± 1 σ
NLO expected ± 2 σ
tan β
cos(β-α)

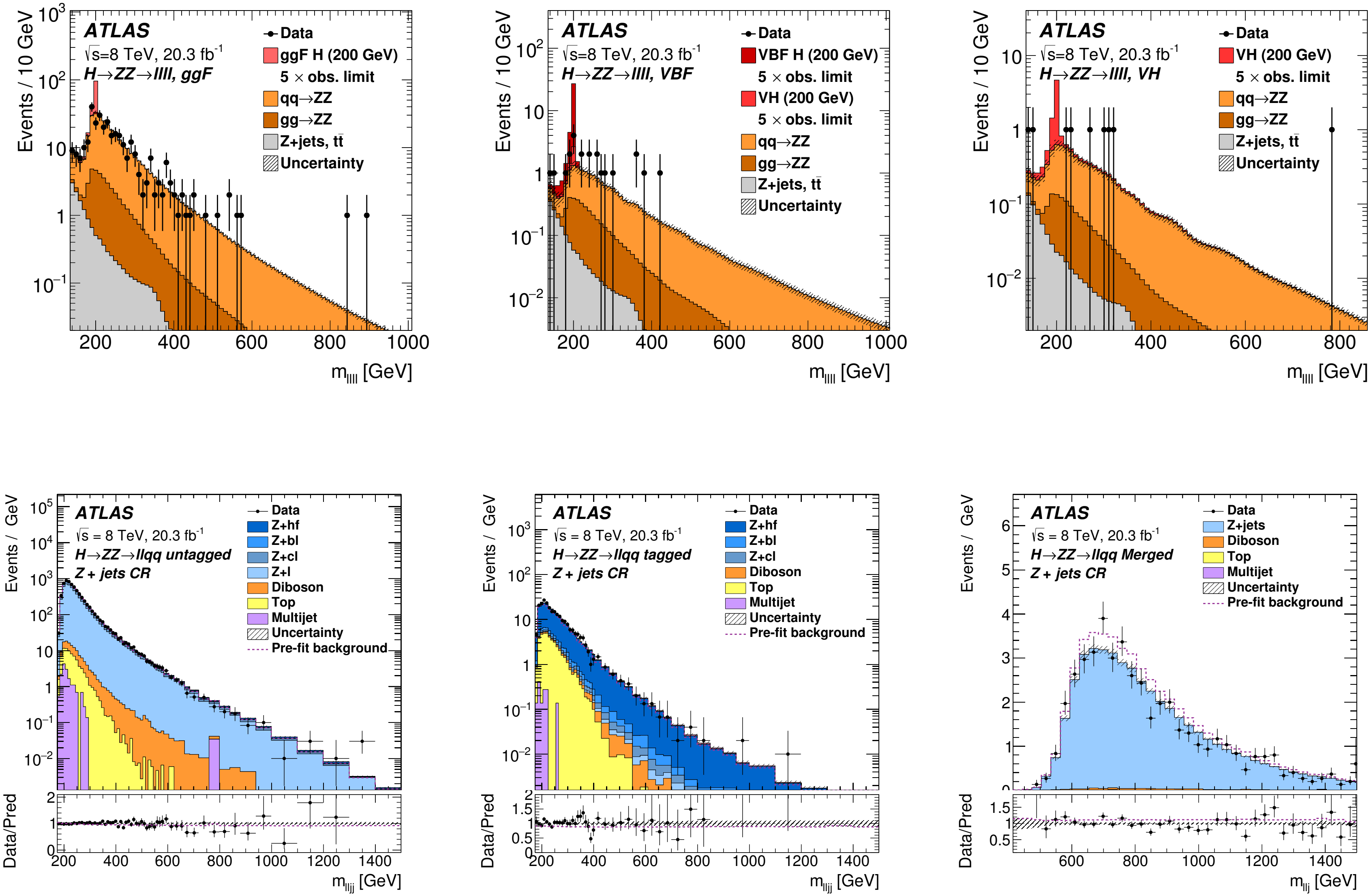

CMS
19.7 fb-1 (8 TeV)
All classes combined - Expected
0.002 pb
0.003 pb
0.004 pb
0.010 pb
0.020 pb
ΓX [GeV]
mX [GeV]
σ B (X → γ γ)95%CL (pb)

Sources of systematic uncertainty	Uncertainty	
Per photon	Barrel	Endcap
Energy resolution, $R_9 > 0.94$ (low η, high η)	0.10%, 0.20%	0.14%, 0.06%
Energy resolution, $R_9 < 0.94$ (low η, high η)	0.10%, 0.18%	0.18%, 0.12%
Photon energy scale	0.5%	2%
Photon identification efficiency	1.0%	2.6%
Per event	Barrel	Endcap
Integrated luminosity	2.6%	2.6%
Vertex finding efficiency	0.2%	0.2%
Trigger efficiency	1.0%	1.0%
R_9 class migration	2.3%	5.5%
Additional normalization uncertainty	5%	5%
Breit–Wigner model	0.01–10%	0.01–10%

Class	η criterion	R_9 criterion
0	$\max(\lvert\eta\rvert) < 1.44$	$\min(R_9) > 0.94$
1	$\max(\lvert\eta\rvert) < 1.44$	$\min(R_9) < 0.94$
2	$1.57 < \max(\lvert\eta\rvert) < 2.50$	$\min(R_9) > 0.94$
3	$1.57 < \max(\lvert\eta\rvert) < 2.50$	$\min(R_9) < 0.94$

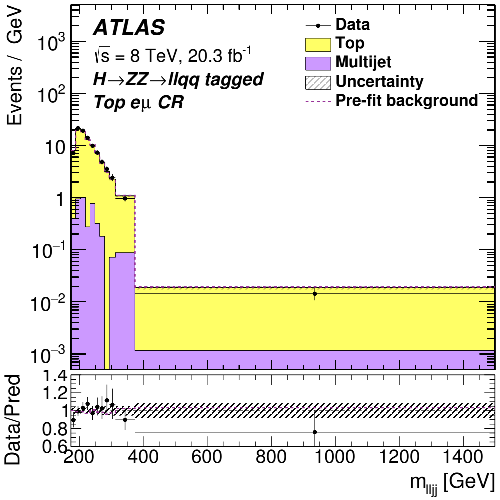
ATLAS searches for new H→ZZ

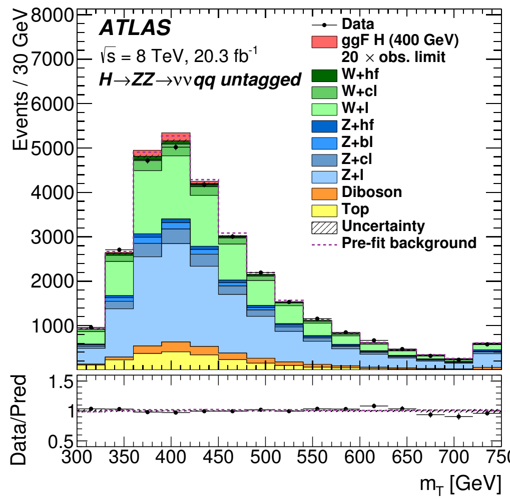
1507.05930

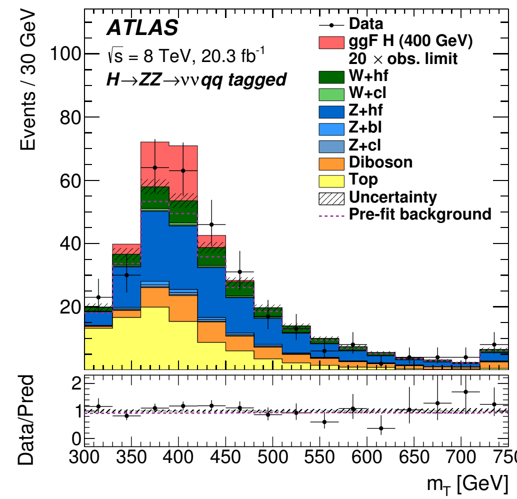


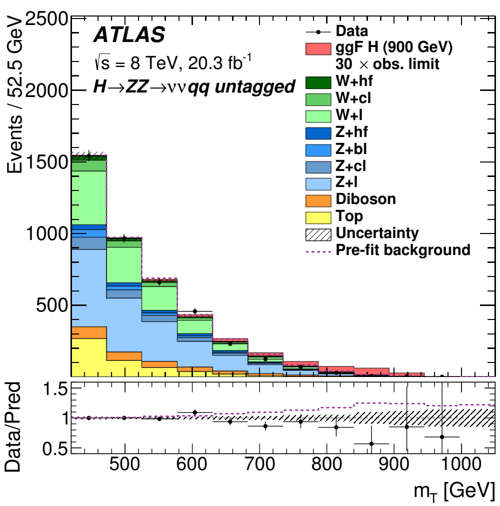
ATLAS searches for new H→ZZ

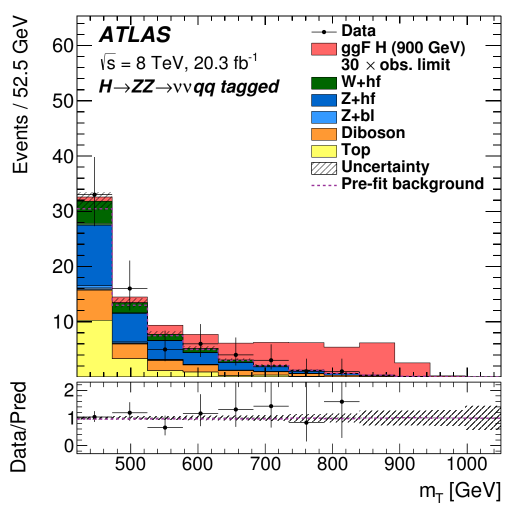
1507.05930

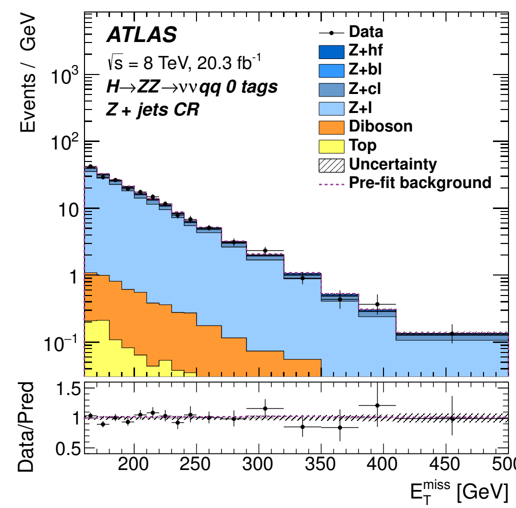


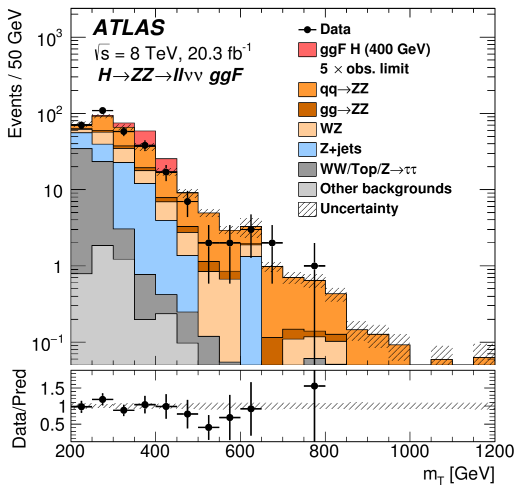


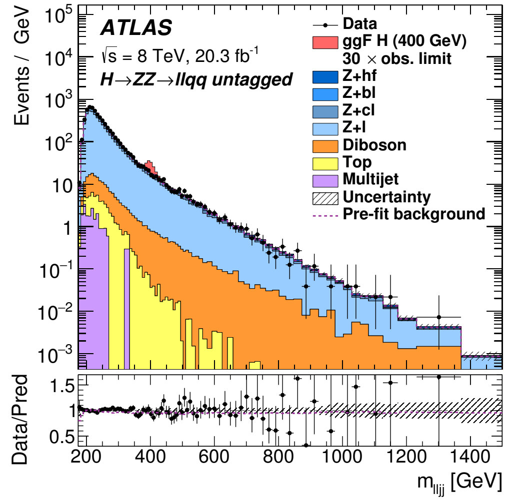


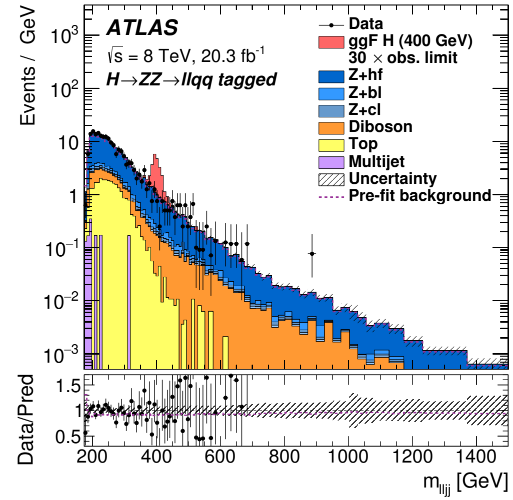


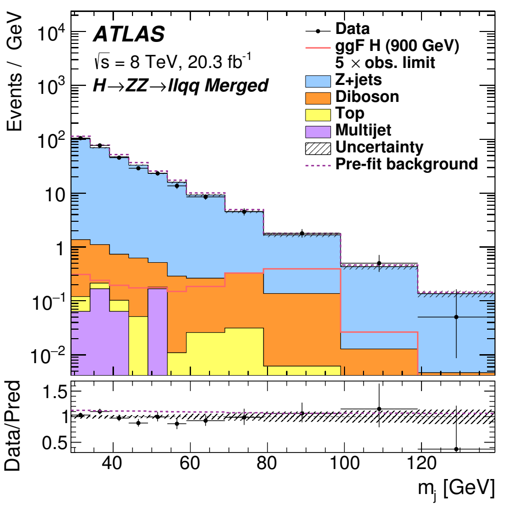


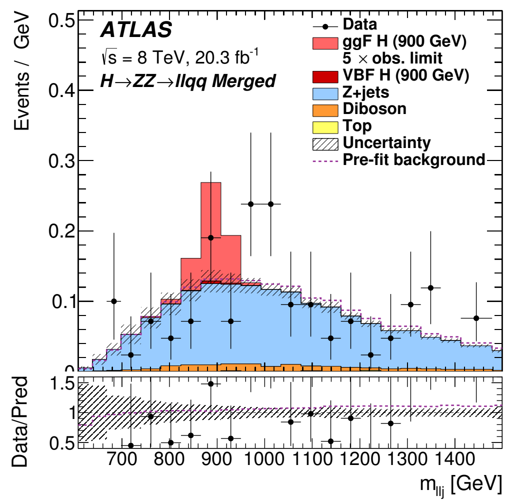


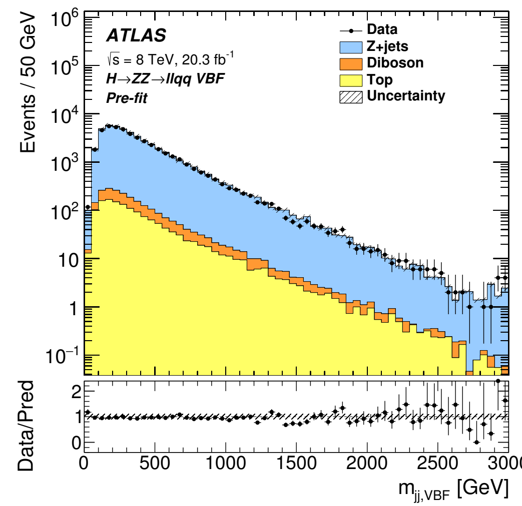

ATLAS
√s = 8 TeV, 20.3 fb-1
H→ZZ→llνν ggF
Data
ggF H (400 GeV)
5 × obs. limit
qq→ZZ
gg→ZZ
WZ
Z+jets
WW/Top/Z→ττ
Other backgrounds
Uncertainty
Events / 50 GeV
Data/Pred
m_T [GeV]


ATLAS
√s = 8 TeV, 20.3 fb-1
H→ZZ→llqq untagged
Data
ggF H (400 GeV)
30 × obs. limit
Z+hf
Z+bl
Z+cl
Z+l
Diboson
Top
Multijet
Uncertainty
Pre-fit background
Events / GeV
Data/Pred
m_lljj [GeV]


ATLAS
√s = 8 TeV, 20.3 fb-1
H→ZZ→llqq tagged
Data
ggF H (400 GeV)
30 × obs. limit
Z+hf
Z+bl
Z+cl
Diboson
Top
Multijet
Uncertainty
Pre-fit background
Events / GeV
Data/Pred
m_lljj [GeV]

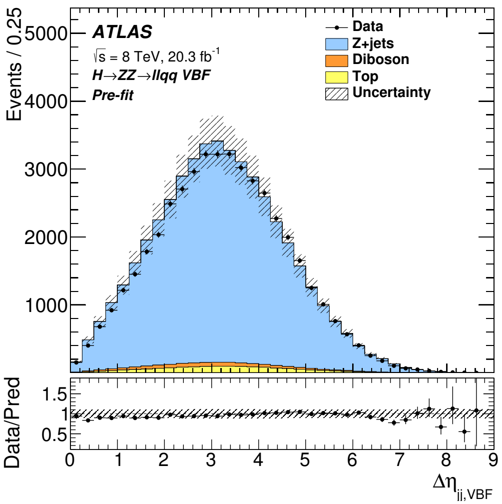

ATLAS
√s = 8 TeV, 20.3 fb-1
H→ZZ→llqq Merged
Data
ggF H (900 GeV)
5 × obs. limit
Z+jets
Diboson
Top
Multijet
Uncertainty
Pre-fit background
Events / GeV
Data/Pred
m_j [GeV]

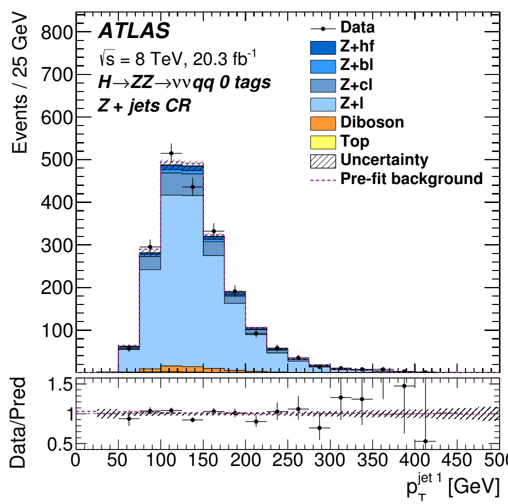

ATLAS
√s = 8 TeV, 20.3 fb-1
H→ZZ→llqq Merged
Data
ggF H (900 GeV)
5 × obs. limit
VBF H (900 GeV)
Z+jets
Diboson
Top
Uncertainty
Pre-fit background
Events / GeV
Data/Pred
m_llj [GeV]

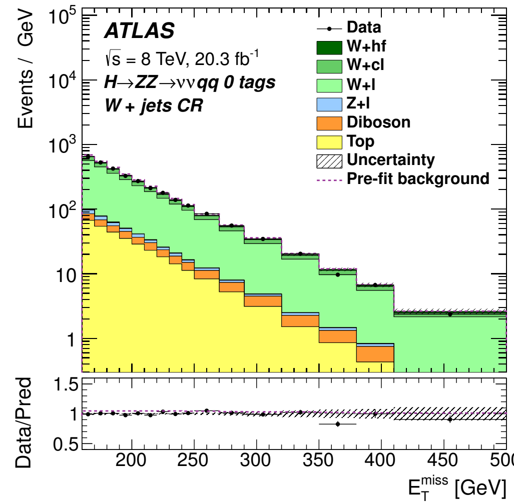

ATLAS
√s = 8 TeV, 20.3 fb-1
H→ZZ→llqq VBF
Pre-fit
Data
Z+jets
Diboson
Top
Uncertainty
Events / 50 GeV
Data/Pred
m_jj,VBF [GeV]

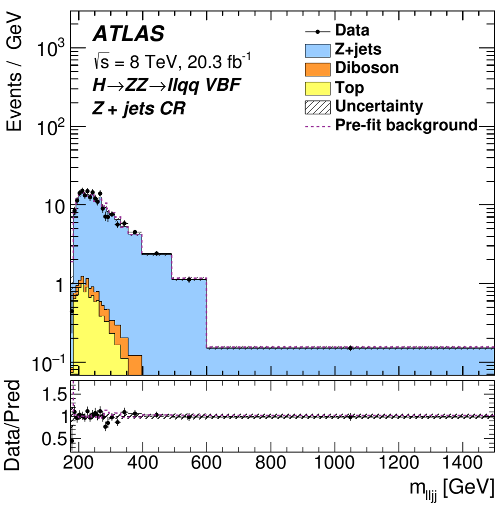
ATLAS searches for new H→ZZ

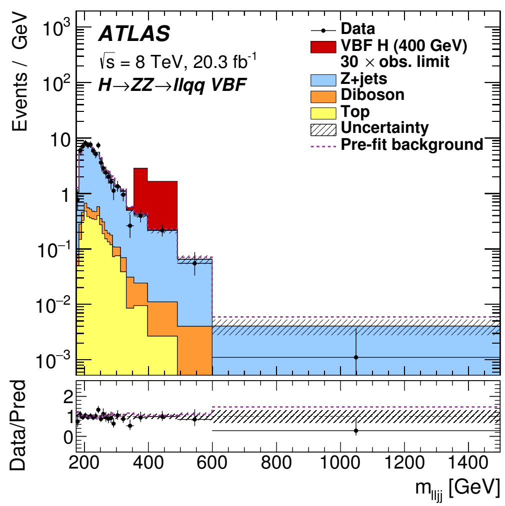
1507.05930

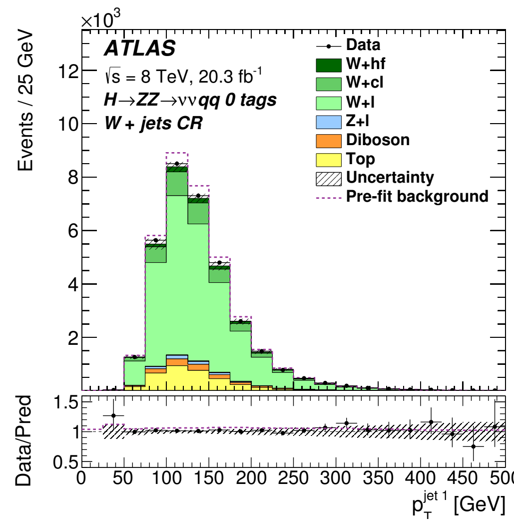






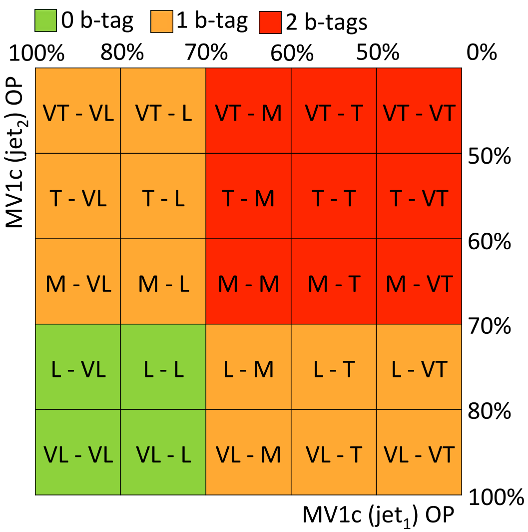


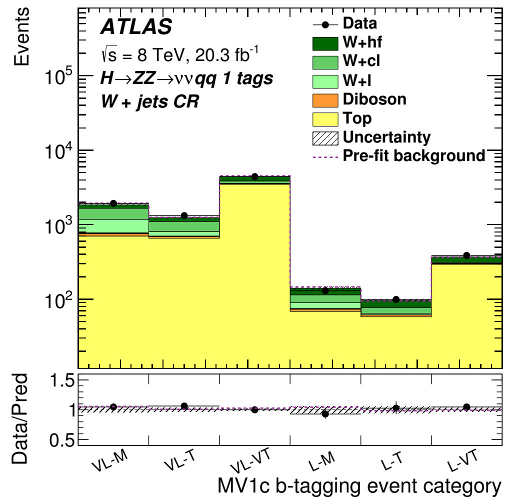


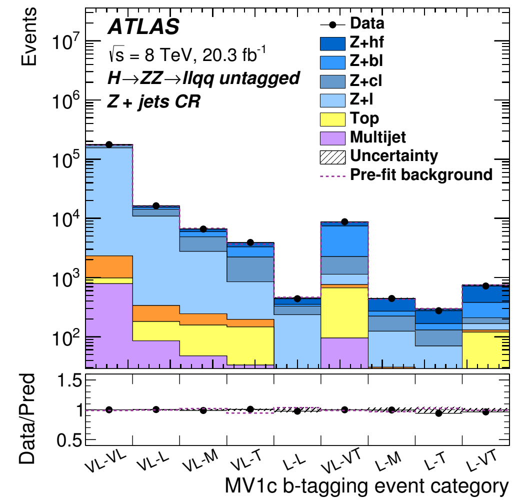


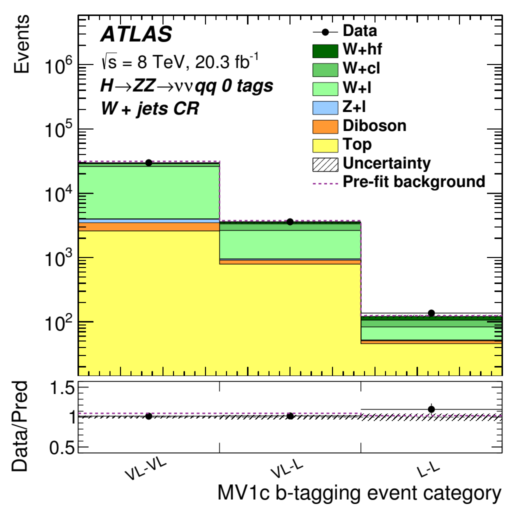
ATLAS searches for new H→ZZ

1507.05930









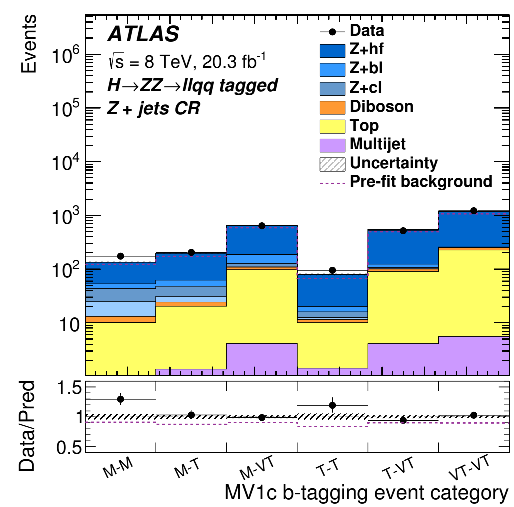
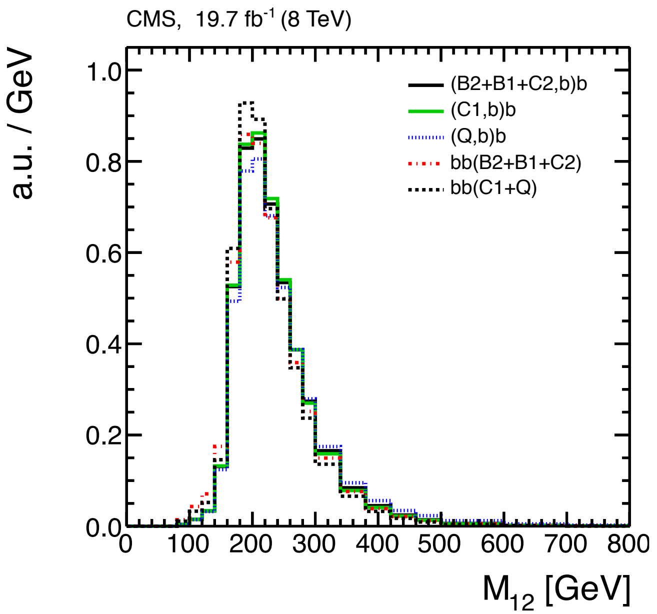


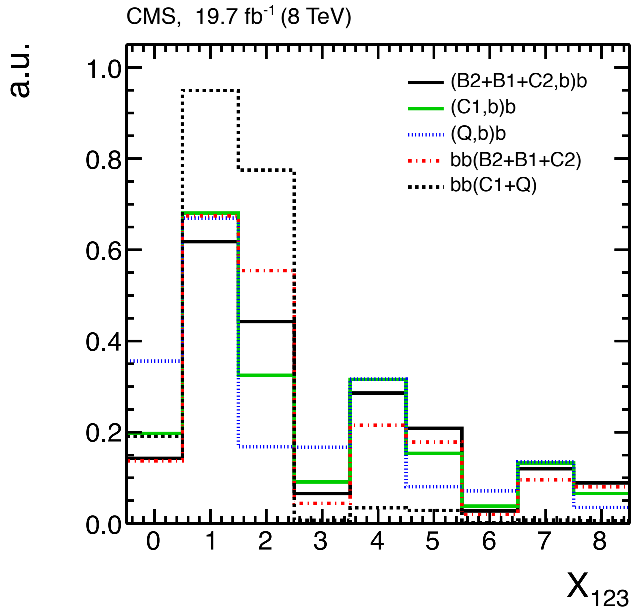
Table 1: Separate sources of systematic uncertainties accounted for in the analysis. The magnitude of the variation of the source that has been applied to the signal model is shown.

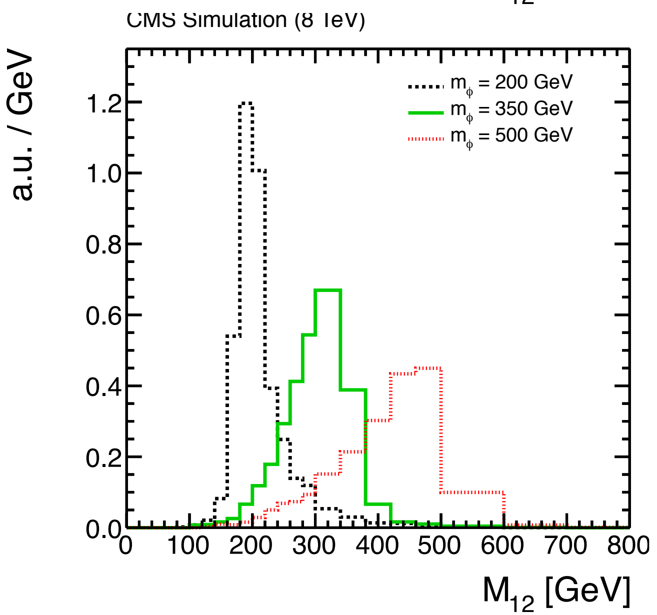
Source	Magnitude
Integrated luminosity	2.6%
Acceptance (PDF)	3.0%
Trigger Efficiency	
- Electron	2%
- Muon	3.5%
Selection Efficiency	
- Photon	1.0–2.6%
- Electron	5.0%
- Muon	2.0%
Signal	
- Mass Scale	1.0%
- Mass Resolution	10.0%
Pileup	1.3%

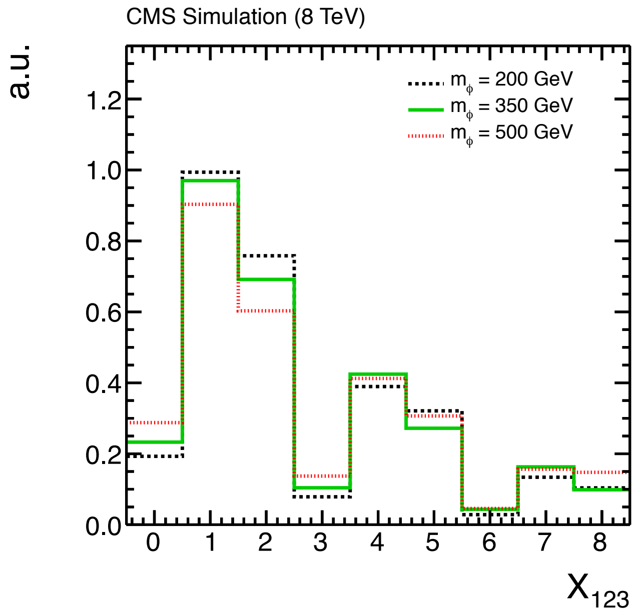
CMS search for MSSM h->bb

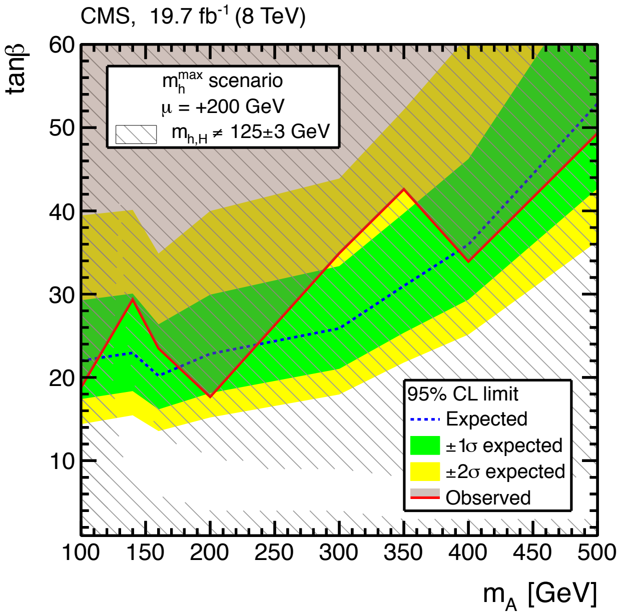
1506.08329



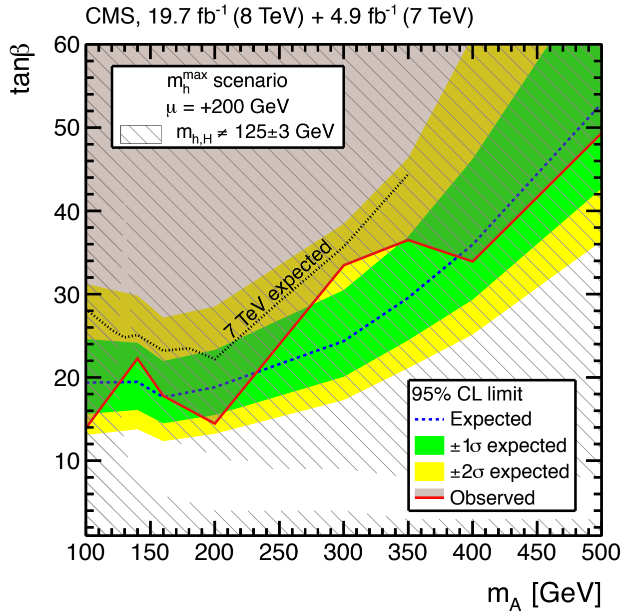




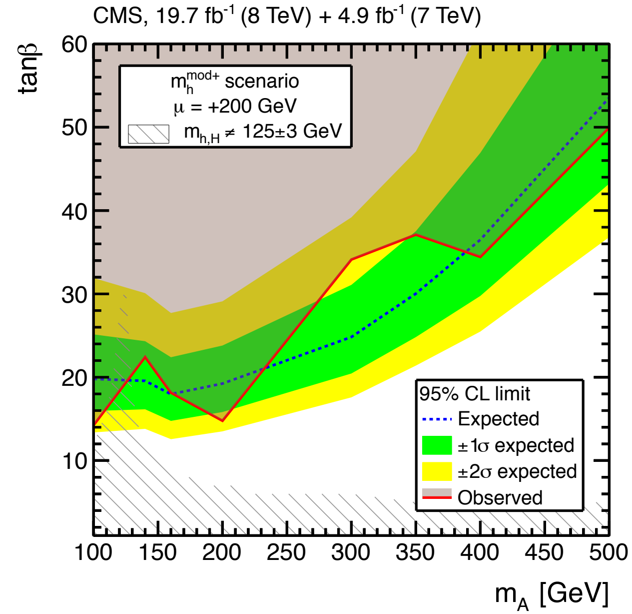




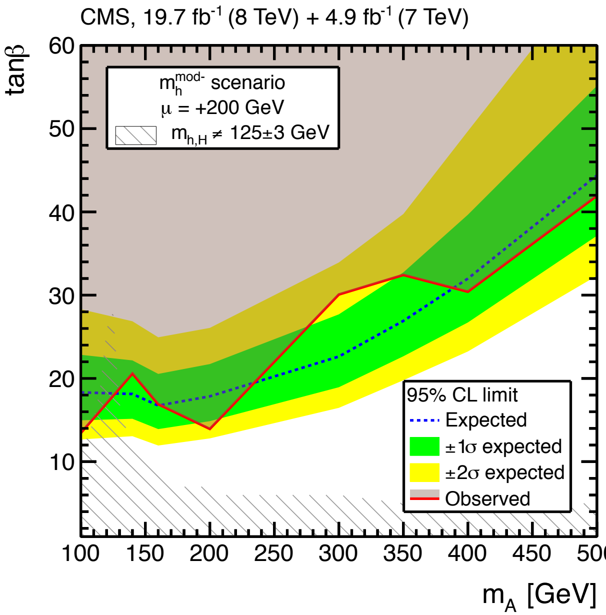
CMS, 19.7 fb-1 (8 TeV)
tanβ
m_h^max scenario
μ = +200 GeV
m_h,H ≠ 125±3 GeV
95% CL limit
Expected
±1σ expected
±2σ expected
Observed
m_A [GeV]



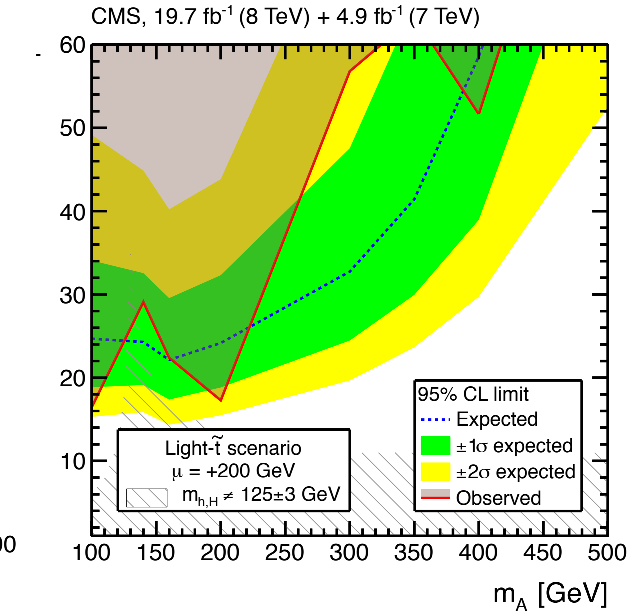
CMS, 19.7 fb-1 (8 TeV) + 4.9 fb-1 (7 TeV)
tanβ
m_h^max scenario
μ = +200 GeV
m_h,H ≠ 125±3 GeV
7 TeV expected
95% CL limit
Expected
±1σ expected
±2σ expected
Observed
m_A [GeV]



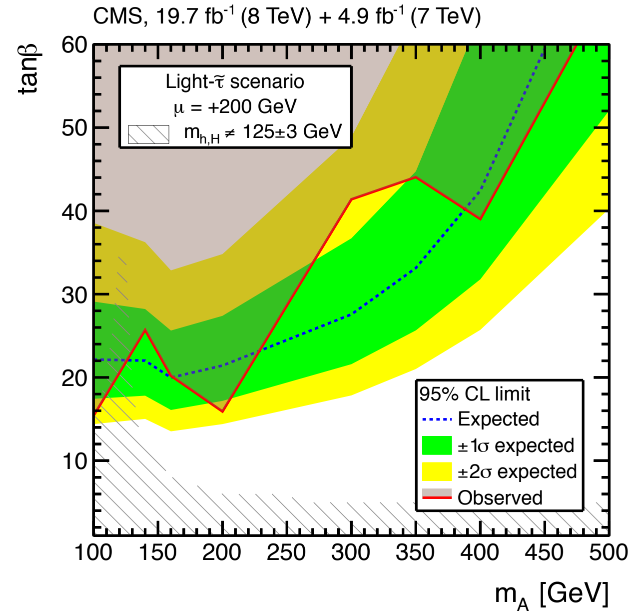
CMS, 19.7 fb-1 (8 TeV) + 4.9 fb-1 (7 TeV)
tanβ
m_h^mod+ scenario
μ = +200 GeV
m_h,H ≠ 125±3 GeV
95% CL limit
Expected
±1σ expected
±2σ expected
Observed
m_A [GeV]



CMS, 19.7 fb-1 (8 TeV) + 4.9 fb-1 (7 TeV)
tanβ
m_h^mod- scenario
μ = +200 GeV
m_h,H ≠ 125±3 GeV
95% CL limit
Expected
±1σ expected
±2σ expected
Observed
m_A [GeV]



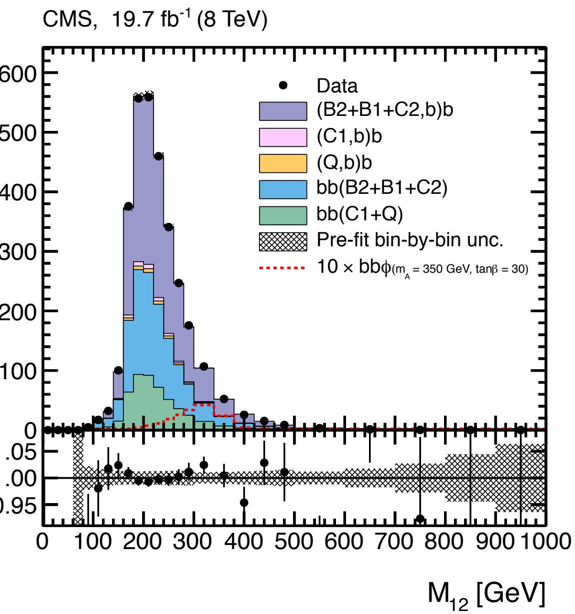
CMS, 19.7 fb-1 (8 TeV) + 4.9 fb-1 (7 TeV)
95% CL limit
Expected
±1σ expected
±2σ expected
Observed
Light-t̃ scenario
μ = +200 GeV
m_h,H ≠ 125±3 GeV
m_A [GeV]

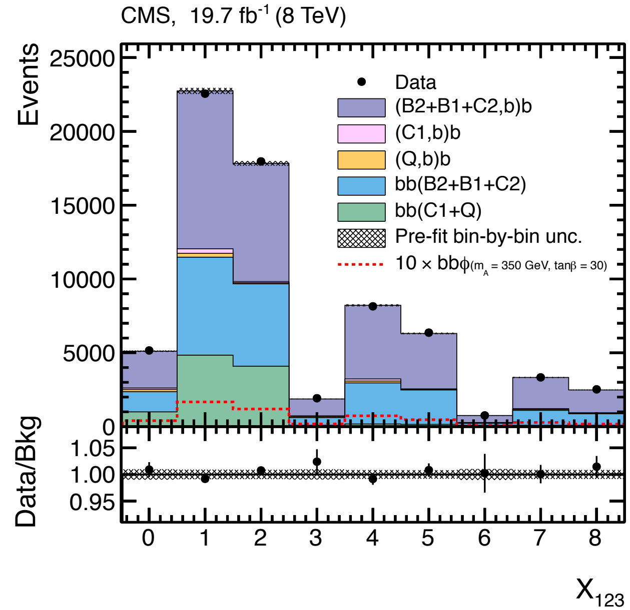


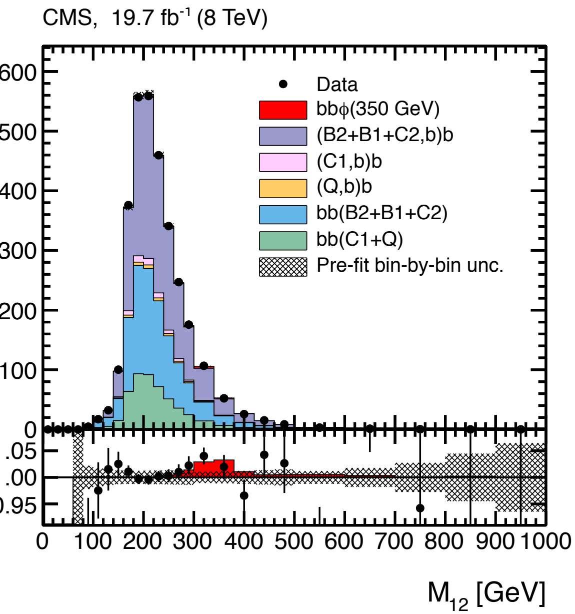
CMS, 19.7 fb-1 (8 TeV) + 4.9 fb-1 (7 TeV)
tanβ
Light-τ̃ scenario
μ = +200 GeV
m_h,H ≠ 125±3 GeV
95% CL limit
Expected
±1σ expected
±2σ expected
Observed
m_A [GeV]

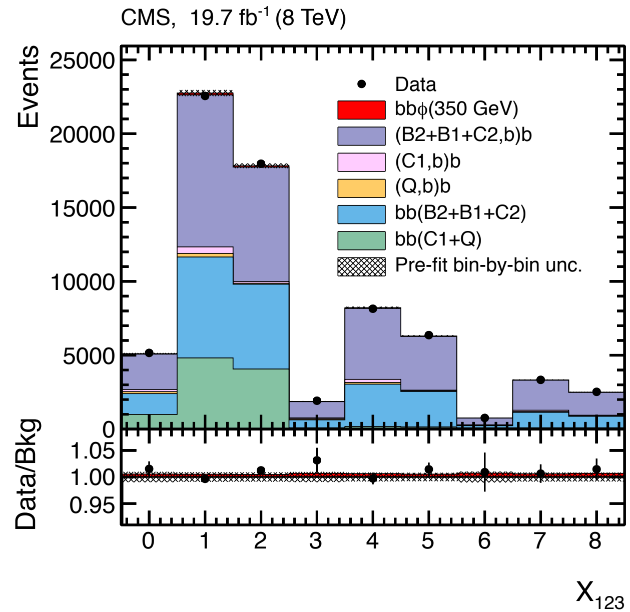
CMS search for MSSM h->bb

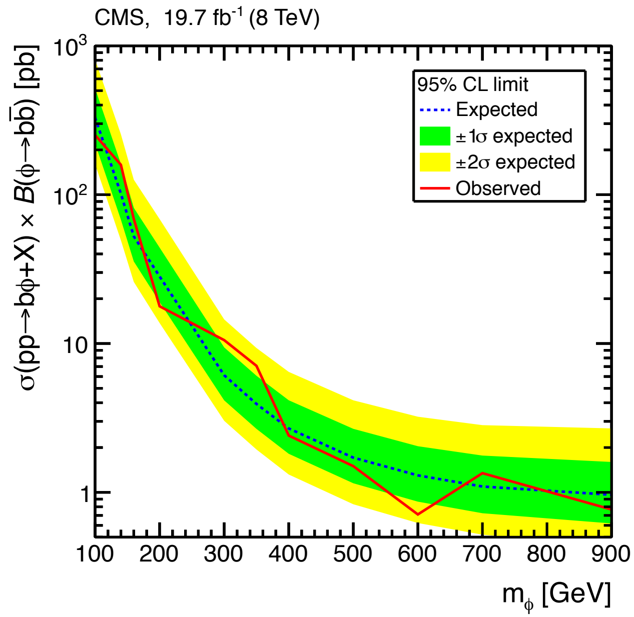
1506.08329



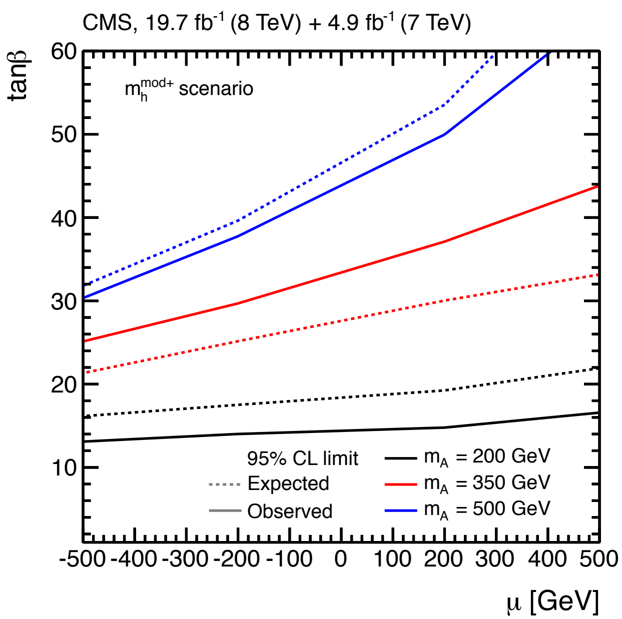




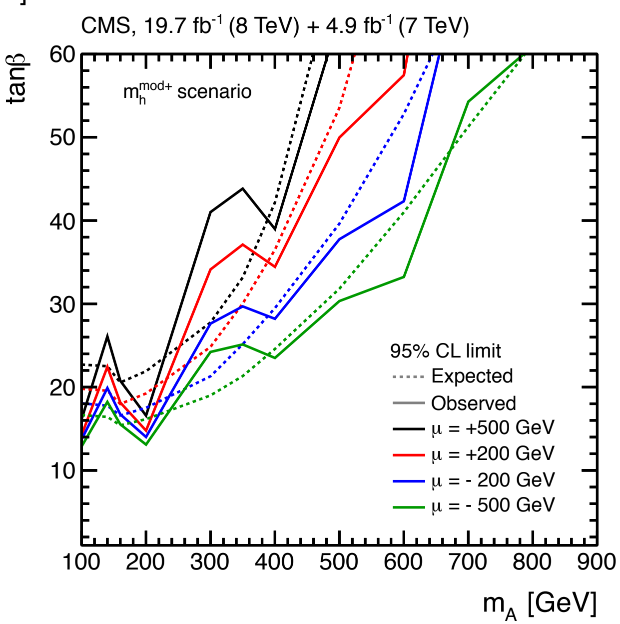




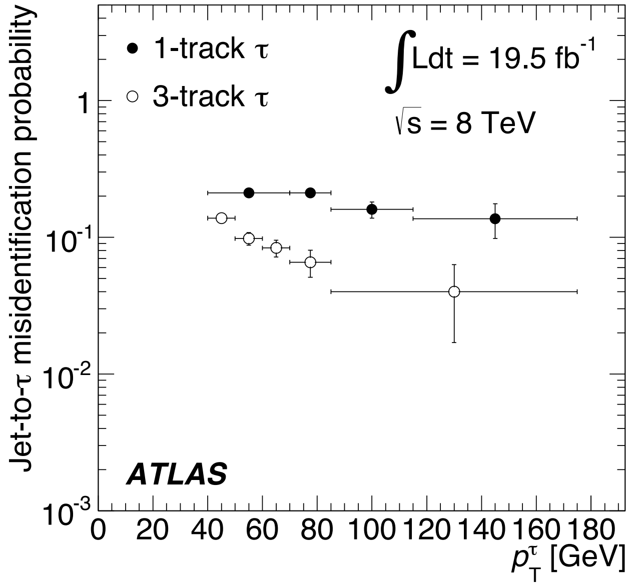
CMS, 19.7 fb-1 (8 TeV)
σ(pp→bϕ+X) × B(ϕ→bb̄) [pb]
95% CL limit
Expected
±1σ expected
±2σ expected
Observed
mϕ [GeV]



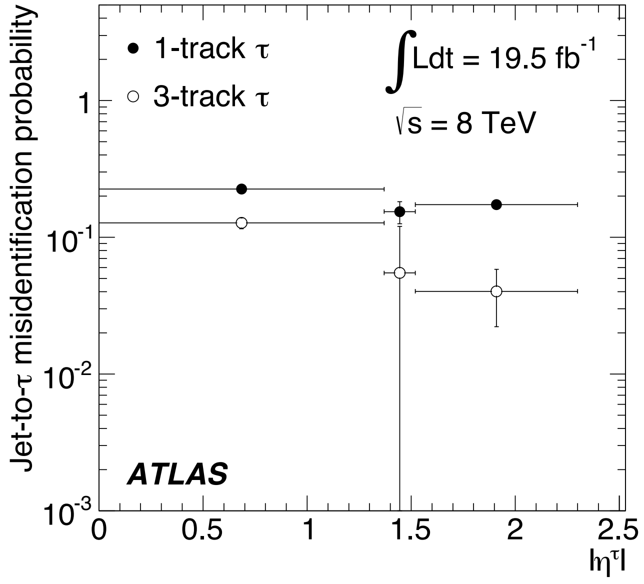
CMS, 19.7 fb-1 (8 TeV) + 4.9 fb-1 (7 TeV)
tanβ
mhmod+ scenario
95% CL limit
Expected
Observed
mA = 200 GeV
mA = 350 GeV
mA = 500 GeV
μ [GeV]



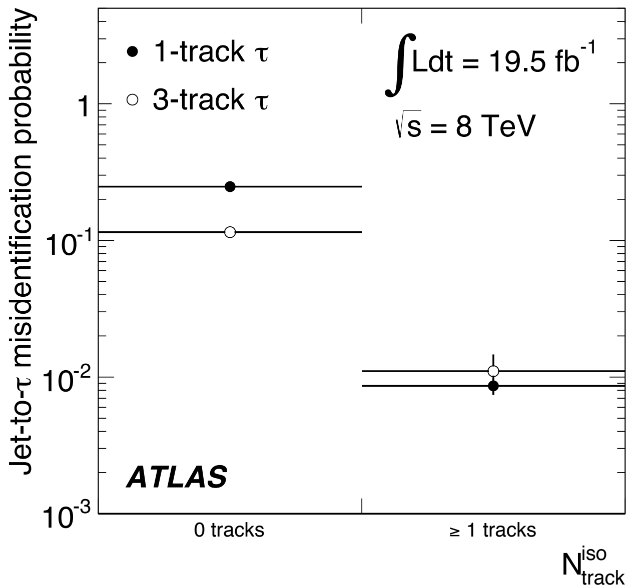
CMS, 19.7 fb-1 (8 TeV) + 4.9 fb-1 (7 TeV)
tanβ
mhmod+ scenario
95% CL limit
Expected
Observed
μ = +500 GeV
μ = +200 GeV
μ = - 200 GeV
μ = - 500 GeV
mA [GeV]



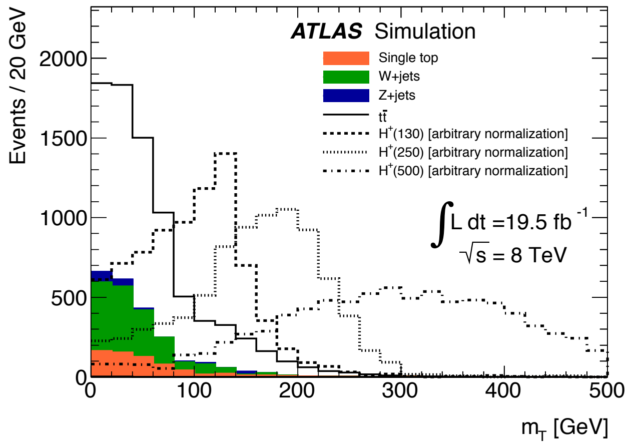
Jet-to-τ misidentification probability
1-track τ
3-track τ
∫Ldt = 19.5 fb-1
√s = 8 TeV
ATLAS
p_T^τ [GeV]



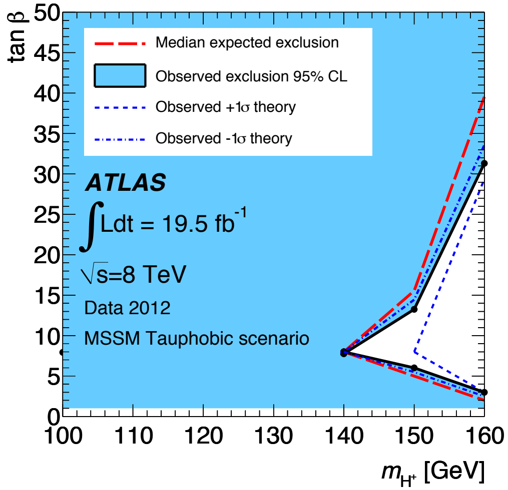
Jet-to-τ misidentification probability
1-track τ
3-track τ
∫Ldt = 19.5 fb-1
√s = 8 TeV
ATLAS
|ητ|

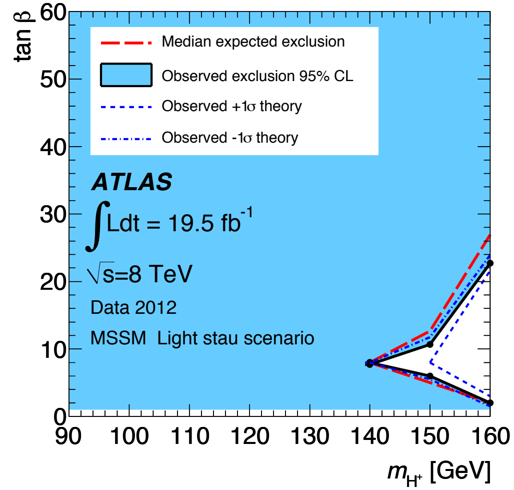


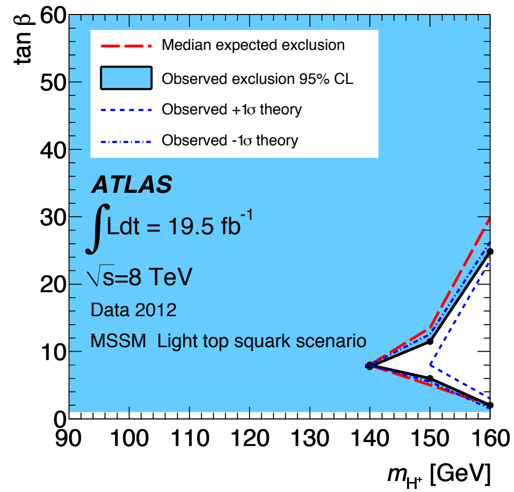
Jet-to-τ misidentification probability
1-track τ
3-track τ
∫Ldt = 19.5 fb-1
√s = 8 TeV
ATLAS
0 tracks
≥ 1 tracks
N_{track}^{iso}

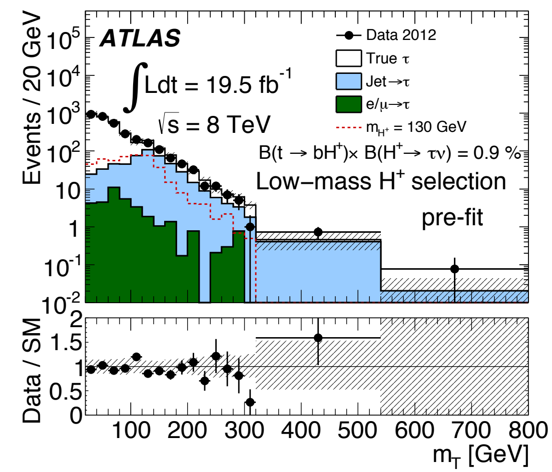


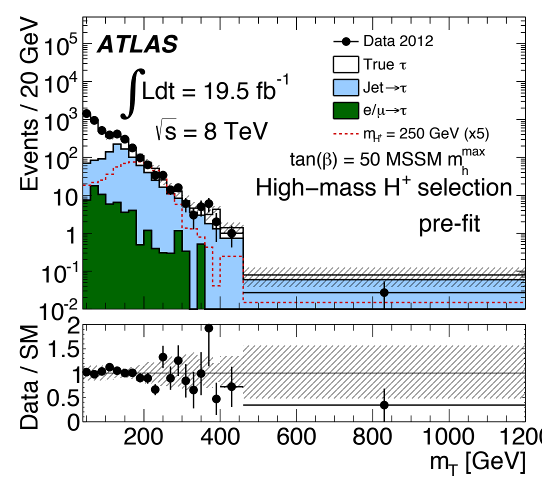
Events / 20 GeV
ATLAS Simulation
Single top
W+jets
Z+jets
tt̄
H+(130) [arbitrary normalization]
H+(250) [arbitrary normalization]
H+(500) [arbitrary normalization]
∫L dt =19.5 fb-1
√s = 8 TeV
m_T [GeV]

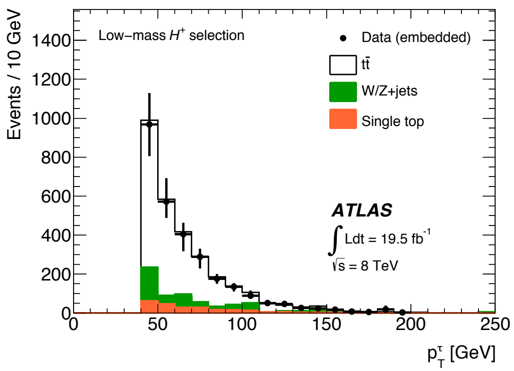

tan β
Median expected exclusion
Observed exclusion 95% CL
Observed +1σ theory
Observed -1σ theory
ATLAS
∫Ldt = 19.5 fb-1
√s=8 TeV
Data 2012
MSSM Tauphobic scenario
m_H+ [GeV]

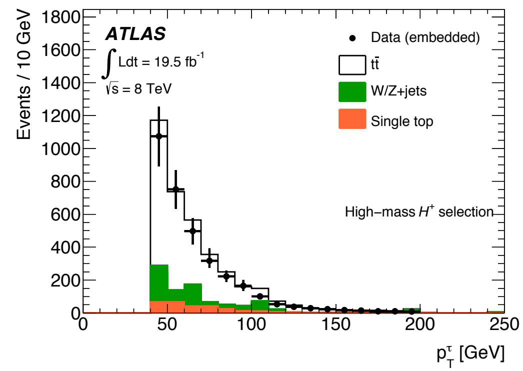

tan β
Median expected exclusion
Observed exclusion 95% CL
Observed +1σ theory
Observed -1σ theory
ATLAS
∫Ldt = 19.5 fb-1
√s=8 TeV
Data 2012
MSSM Light stau scenario
m_H+ [GeV]

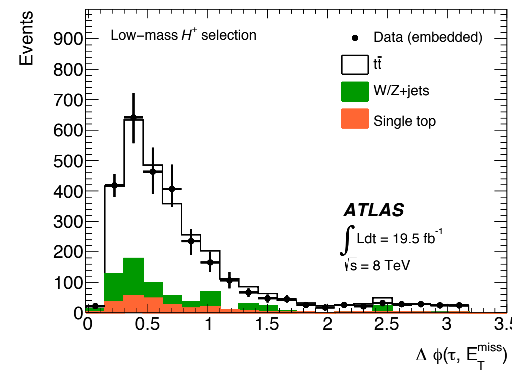

tan β
Median expected exclusion
Observed exclusion 95% CL
Observed +1σ theory
Observed -1σ theory
ATLAS
∫Ldt = 19.5 fb-1
√s=8 TeV
Data 2012
MSSM Light top squark scenario
m_H+ [GeV]

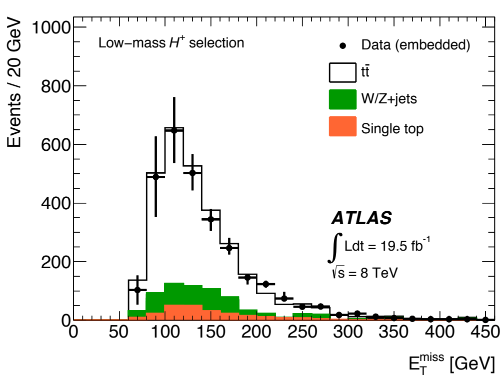

Events / 20 GeV
ATLAS
∫Ldt = 19.5 fb-1
√s = 8 TeV
Data 2012
True τ
Jet→τ
e/μ→τ
m_H+ = 130 GeV
B(t → bH+)× B(H+→ τν) = 0.9 %
Low−mass H+ selection
pre-fit
Data / SM
m_T [GeV]

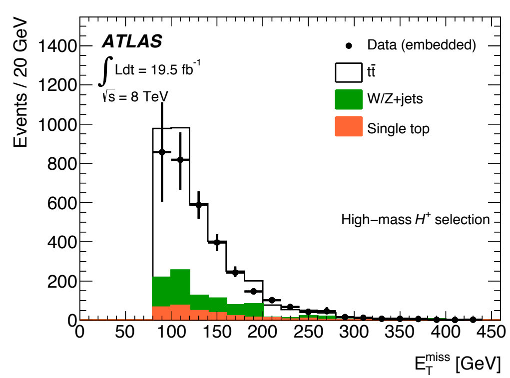

Events / 20 GeV
ATLAS
∫Ldt = 19.5 fb-1
√s = 8 TeV
Data 2012
True τ
Jet→τ
e/μ→τ
m_H+ = 250 GeV (x5)
tan(β) = 50 MSSM m_h^max
High−mass H+ selection
pre-fit
Data / SM
m_T [GeV]

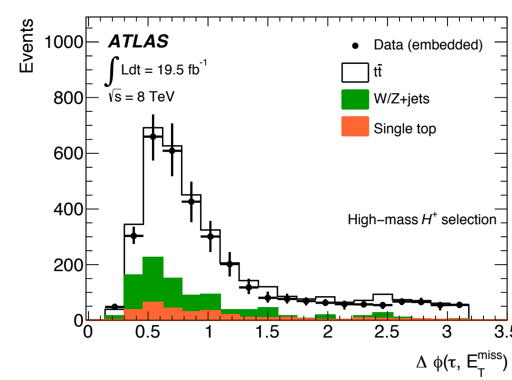

Events / 10 GeV
Low−mass H+ selection
Data (embedded)
tt̄
W/Z+jets
Single top
ATLAS
∫Ldt = 19.5 fb-1
√s = 8 TeV
pTτ [GeV]


Events / 10 GeV
ATLAS
∫Ldt = 19.5 fb-1
√s = 8 TeV
Data (embedded)
tt̄
W/Z+jets
Single top
High−mass H+ selection
pTτ [GeV]

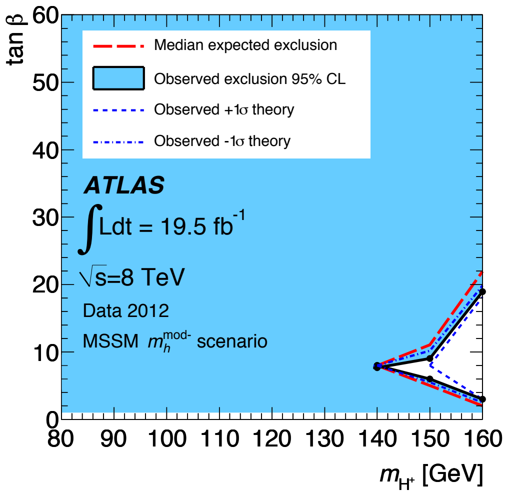

Events
Low−mass H+ selection
Data (embedded)
tt̄
W/Z+jets
Single top
ATLAS
∫Ldt = 19.5 fb-1
√s = 8 TeV
Δ φ(τ, ETmiss)

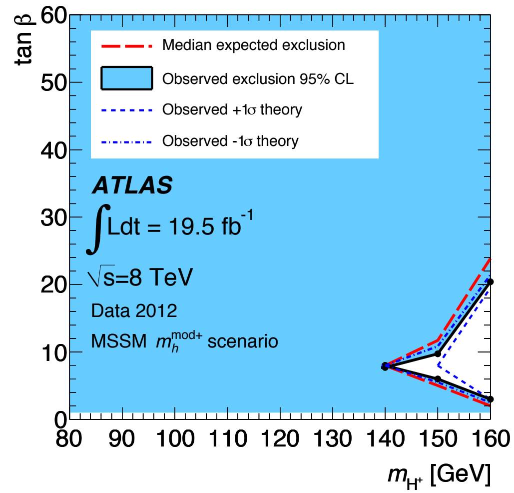

Events / 20 GeV
Low−mass H+ selection
Data (embedded)
tt̄
W/Z+jets
Single top
ATLAS
∫Ldt = 19.5 fb-1
√s = 8 TeV
ETmiss [GeV]

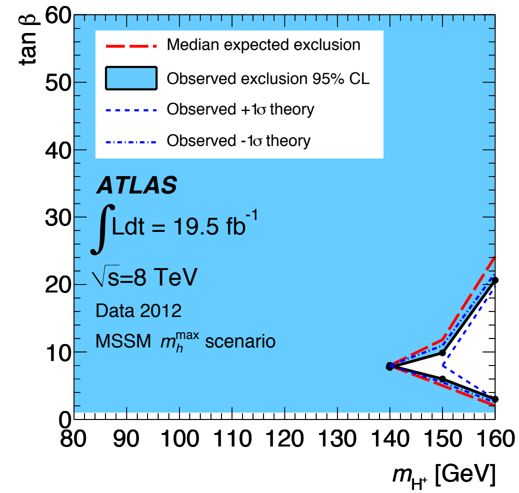

Events / 20 GeV
ATLAS
∫Ldt = 19.5 fb-1
√s = 8 TeV
Data (embedded)
tt̄
W/Z+jets
Single top
High−mass H+ selection
ETmiss [GeV]

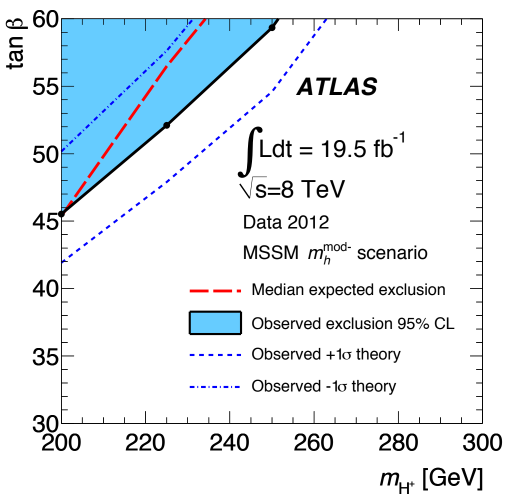

Events
ATLAS
∫Ldt = 19.5 fb-1
√s = 8 TeV
Data (embedded)
tt̄
W/Z+jets
Single top
High−mass H+ selection
Δ φ(τ, ETmiss)

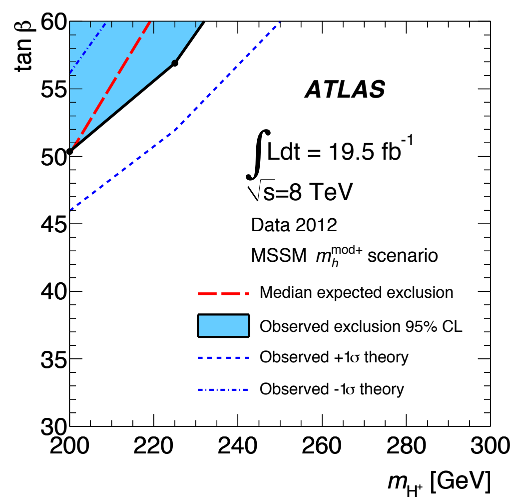
ATLAS search for $H^+ \to \tau\nu$ in all-hadronic state 1412.6663

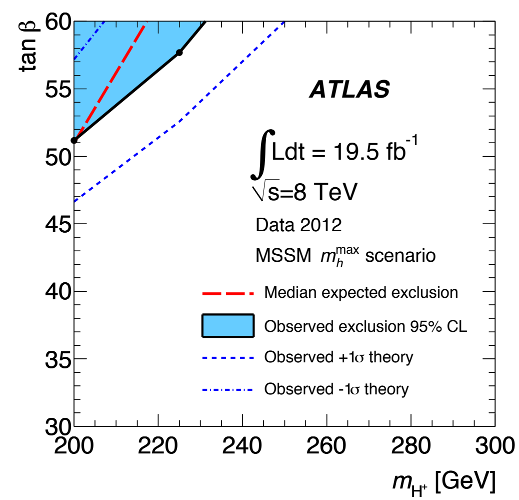




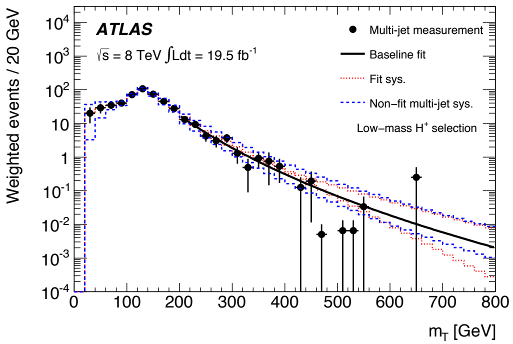


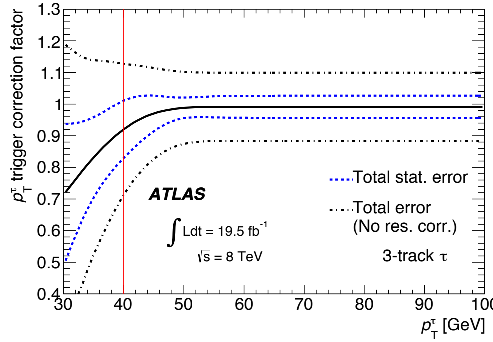


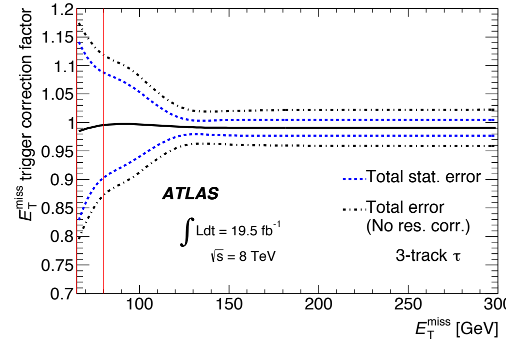


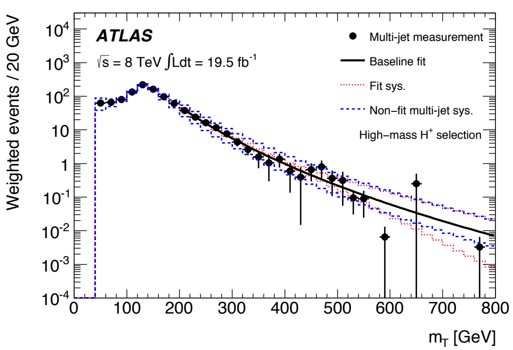


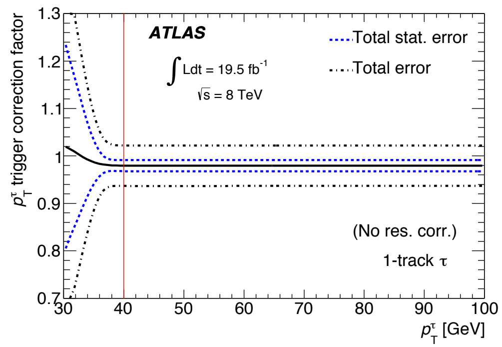
ATLAS search for $H^+ \to \tau\nu$ in all-hadronic state 1412.6663

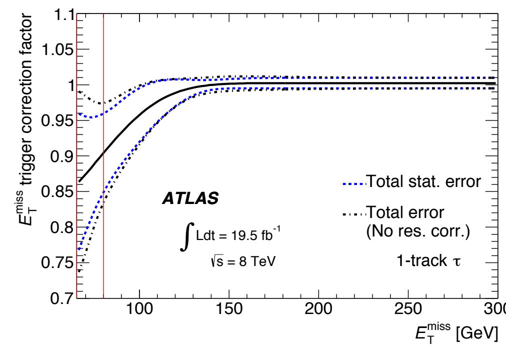


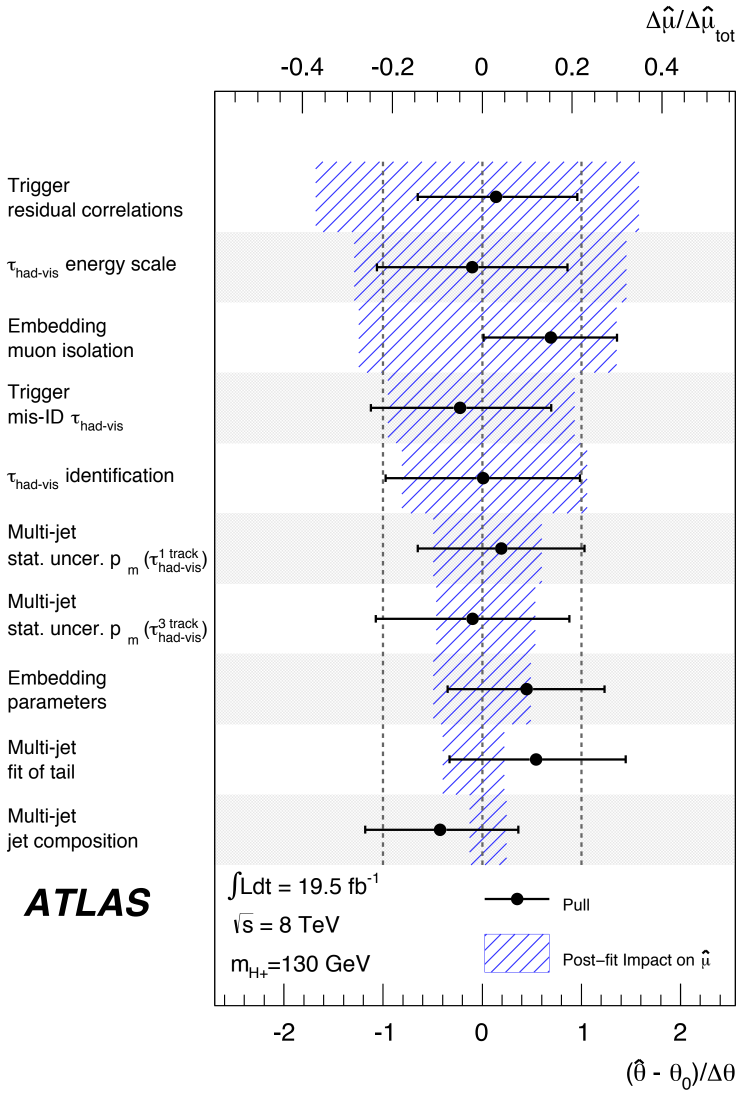


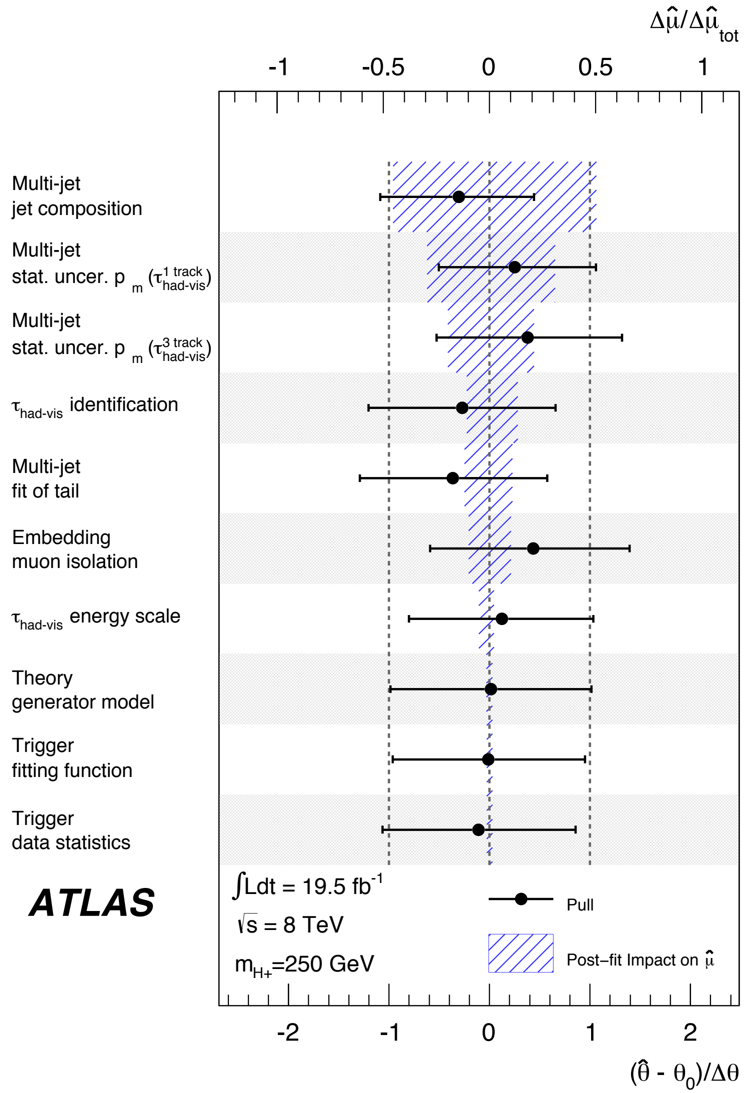


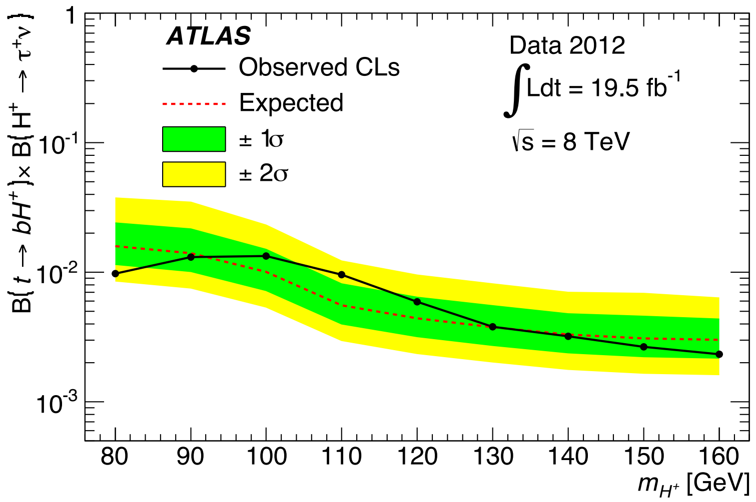


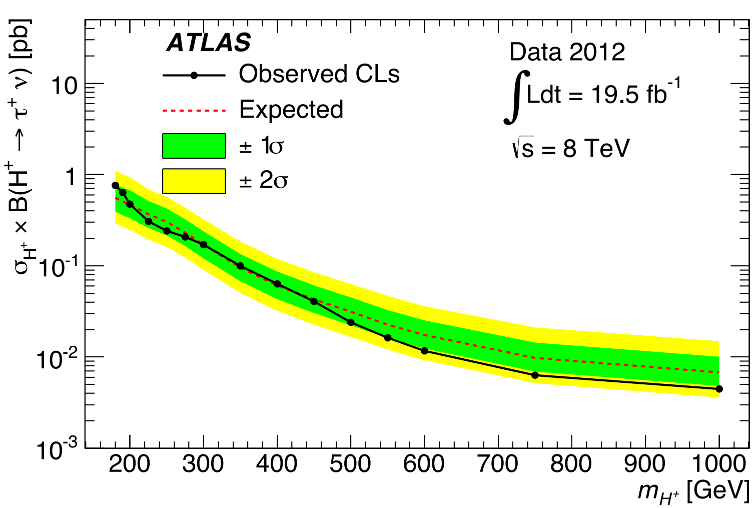





$\Delta\hat{\mu}/\Delta\hat{\mu}_{tot}$
-0.4
-0.2
0
0.2
0.4
Trigger residual correlations
$\tau_{had-vis}$ energy scale
Embedding muon isolation
Trigger mis-ID $\tau_{had-vis}$
$\tau_{had-vis}$ identification
Multi-jet stat. uncer. p_m ($\tau^{1\ track}_{had-vis}$)
Multi-jet stat. uncer. p_m ($\tau^{3\ track}_{had-vis}$)
Embedding parameters
Multi-jet fit of tail
Multi-jet jet composition
ATLAS
$\int Ldt = 19.5\ fb^{-1}$
$\sqrt{s}$ = 8 TeV
m_{H+}=130 GeV
Pull
Post−fit Impact on $\hat{\mu}$
-2
-1
0
1
2
$(\hat{\theta} - \theta_0)/\Delta\theta$


$\Delta\hat{\mu}/\Delta\hat{\mu}_{tot}$
-1
-0.5
0
0.5
1
Multi-jet jet composition
Multi-jet stat. uncer. p_m ($\tau^{1\ track}_{had-vis}$)
Multi-jet stat. uncer. p_m ($\tau^{3\ track}_{had-vis}$)
$\tau_{had-vis}$ identification
Multi-jet fit of tail
Embedding muon isolation
$\tau_{had-vis}$ energy scale
Theory generator model
Trigger fitting function
Trigger data statistics
ATLAS
$\int Ldt = 19.5\ fb^{-1}$
$\sqrt{s}$ = 8 TeV
m_{H+}=250 GeV
Pull
Post−fit Impact on $\hat{\mu}$
-2
-1
0
1
2
$(\hat{\theta} - \theta_0)/\Delta\theta$


ATLAS
Observed CLs
Expected
± 1σ
± 2σ
Data 2012
∫Ldt = 19.5 fb-1
√s = 8 TeV
B(t → bH+)× B(H+ → τ+ν)
1
10-1
10-2
10-3
80
90
100
110
120
130
140
150
160
mH+ [GeV]

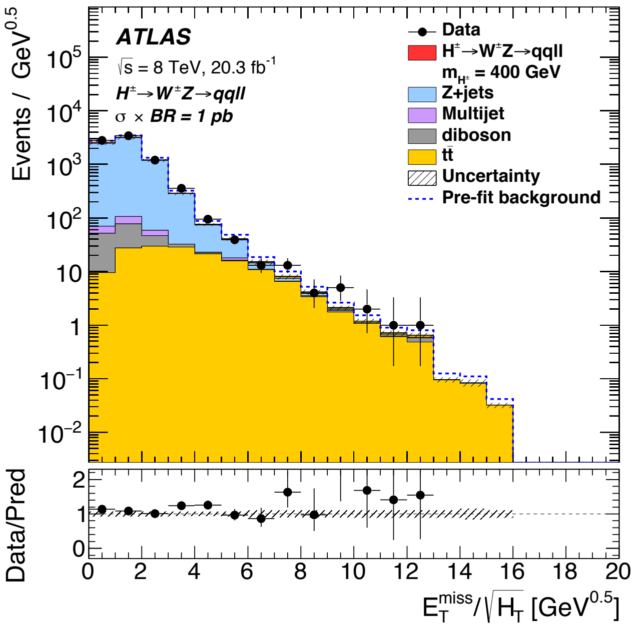

ATLAS
Observed CLs
Expected
± 1σ
± 2σ
Data 2012
∫Ldt = 19.5 fb-1
√s = 8 TeV
σH+ × B(H+ → τ+ ν) [pb]
10
1
10-1
10-2
10-3
200
300
400
500
600
700
800
900
1000
mH+ [GeV]

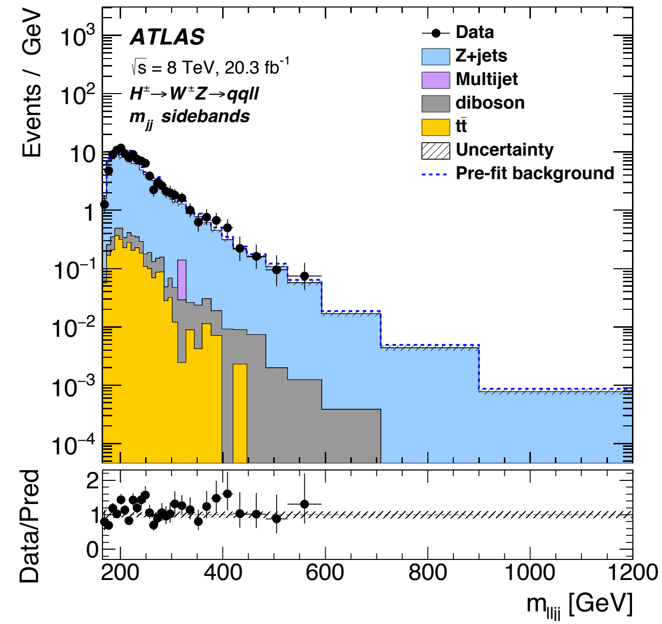
$m_H^\pm$ [GeV]	Expected limit [fb] for given $\Gamma_{H^\pm}/m_{H^\pm}$[%]								
	0	1	2	3	4	5	6	10	15
200	667	765	869	973	1.08×10^3	1.18×10^3	1.29×10^3	1.71×10^3	2.16×10^3
220	745	830	923	1.02×10^3	1.12×10^3	1.22×10^3	1.33×10^3	1.79×10^3	2.41×10^3
240	565	637	713	790	866	945	1.02×10^3	1.36×10^3	1.81×10^3
260	499	552	607	661	716	771	825	1.05×10^3	1.32×10^3
280	347	390	431	473	514	555	596	760	952
300	334	367	399	430	459	488	516	624	751
320	225	249	273	296	319	341	363	446	540
340	225	245	264	282	299	316	333	395	465
360	178	194	208	223	237	250	264	313	368
380	143	155	166	178	189	200	211	251	297
400	132	142	152	161	171	181	190	224	262
420	119	127	135	143	151	158	166	194	225
440	108	116	123	130	137	143	150	174	199
460	90.0	97.6	105	112	118	124	130	152	174
480	93.4	97.8	102	107	111	116	120	138	157
500	72.9	79.3	85.3	91.0	96.5	102	107	124	142
520	81.8	85.5	89.2	92.8	96.4	100	103	117	132
540	71.3	76.0	80.3	84.4	88.3	92.0	95.5	108	122
560	64.8	68.8	72.8	76.6	80.2	83.7	87.1	99.0	111
580	72.7	75.5	78.3	80.9	83.3	85.6	87.9	96.3	105
600	67.2	70.2	72.8	75.1	77.4	79.5	81.4	88.9	97.0
650	55.7	57.9	60.2	62.4	64.5	66.7	68.7	76.1	83.6
700	64.7	65.5	66.3	67.1	68.0	68.9	69.8	73.5	77.9
750	47.5	49.6	51.7	53.6	55.4	57.2	58.9	65.0	71.0
800	55.9	57.5	58.9	60.4	61.7	63.1	64.5	69.8	75.7
850	68.5	70.0	71.4	72.6	73.6	74.7	75.7	79.8	84.8
900	84.6	85.5	86.5	87.5	88.6	89.6	90.8	95.2	101
950	88.8	92.6	96.1	99.9	103	106	109	119	130
1000	120	123	127	130	134	137	141	154	171

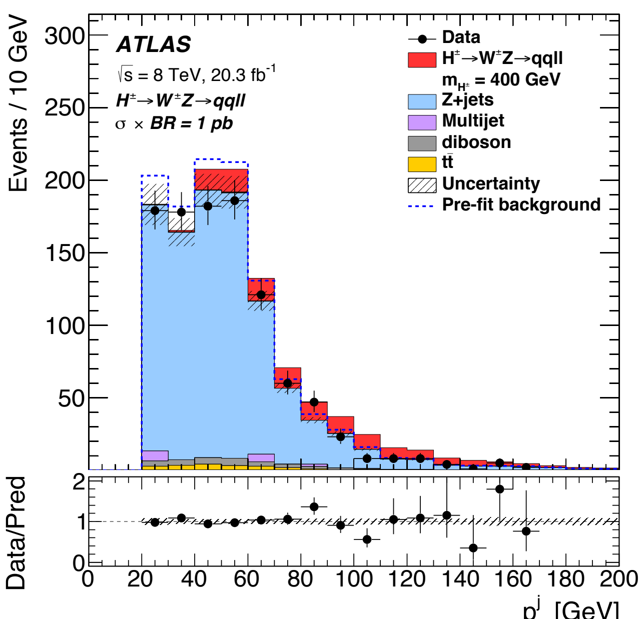
$m_{H^\pm}$ [GeV]	Observed limit [fb] for given $\Gamma_{H^\pm}/m_{H^\pm}$[%]								
	0	1	2	3	4	5	6	10	15
200	517	592	673	753	834	915	996	1.31×10^3	1.67×10^3
220	1.02×10^3	1.15×10^3	1.28×10^3	1.42×10^3	1.56×10^3	1.70×10^3	1.84×10^3	2.42×10^3	3.08×10^3
240	810	909	1.01×10^3	1.11×10^3	1.20×10^3	1.30×10^3	1.39×10^3	1.73×10^3	2.09×10^3
260	347	383	423	465	508	552	598	792	1.04×10^3
280	349	386	421	456	490	523	556	680	817
300	376	400	421	443	460	477	494	558	638
320	142	162	182	203	223	244	265	345	436
340	214	230	244	259	273	288	303	360	426
360	211	227	243	257	271	284	296	341	386
380	169	184	198	212	224	236	247	285	322
400	146	157	167	177	187	197	206	240	274
420	113	121	129	138	147	155	163	193	225
440	98.1	107	115	123	131	139	146	173	198
460	103	110	117	123	129	134	139	158	177
480	107	111	115	120	124	128	132	145	160
500	77.0	84.7	91.6	98.2	104	109	114	129	141
520	92.1	95.7	99.1	102	106	108	111	120	127
540	84.3	87.9	90.8	93.9	96.4	98.5	100	106	111
560	73.1	75.2	77.2	79.3	81.0	82.3	83.9	87.8	90.5
580	68.2	68.5	68.9	69.4	69.7	70.4	70.8	73.2	76.2
600	42.3	44.7	46.8	48.6	50.3	51.8	53.1	57.7	62.2
650	31.4	32.4	33.4	34.5	35.5	36.6	37.6	41.5	46.1
700	34.2	34.7	35.2	35.7	36.3	36.8	37.4	39.8	42.8
750	33.2	34.0	34.7	35.3	36.0	36.7	37.3	39.9	42.7
800	39.6	40.2	40.8	41.4	42.0	42.6	43.2	45.6	48.7
850	48.0	48.7	49.3	49.8	50.4	51.0	51.5	54.0	56.7
900	61.3	62.0	62.6	63.2	63.8	64.5	65.2	67.8	71.4
950	78.1	79.4	81.0	82.6	84.0	85.4	86.7	91.5	97.3
1000	108	110	112	113	115	117	119	126	136

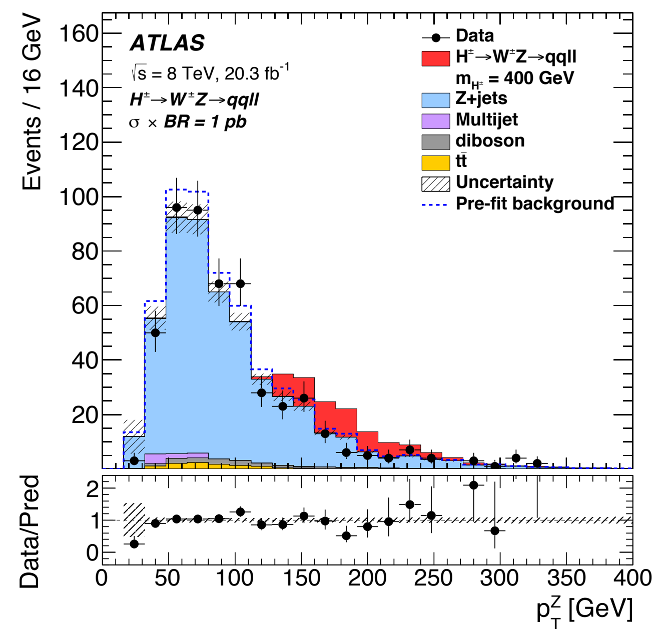
Source of uncertainty	Impact (%)
Total	20
Statistical	14
Systematic	14
Experimental Uncertainties	
Jets+E_T^{miss}	8.8
Luminosity	2.8
Leptons	0.9
b-tagging	0.2
Theoretical and Modeling Uncertainties	
Signal	10
Top	3.8
Z+jets	3.7
Multijet	0.1

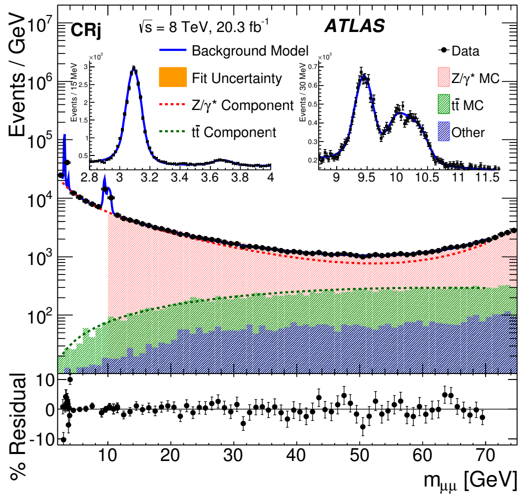
ATLAS search for $H^{+} \rightarrow W^{+}Z$ in VBF 1503.04233

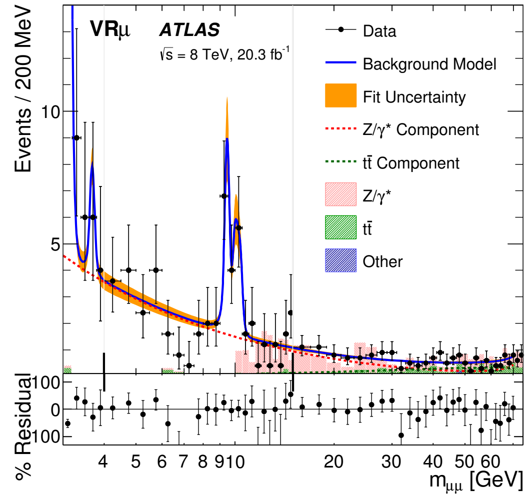


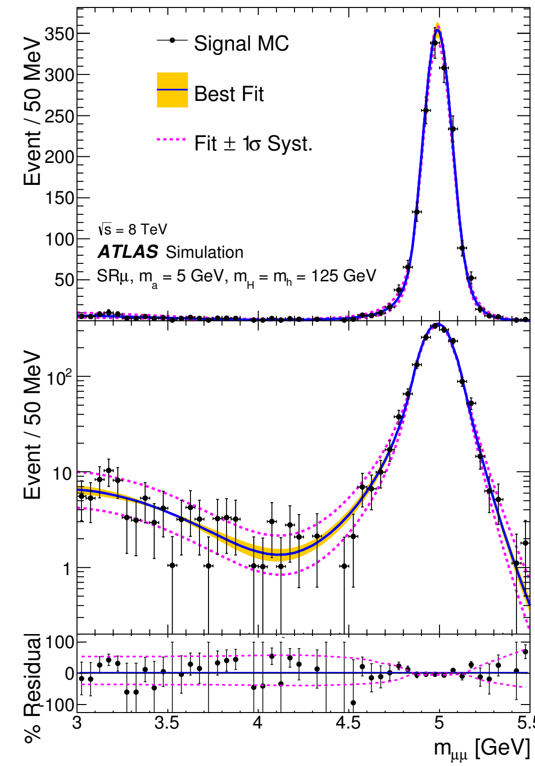


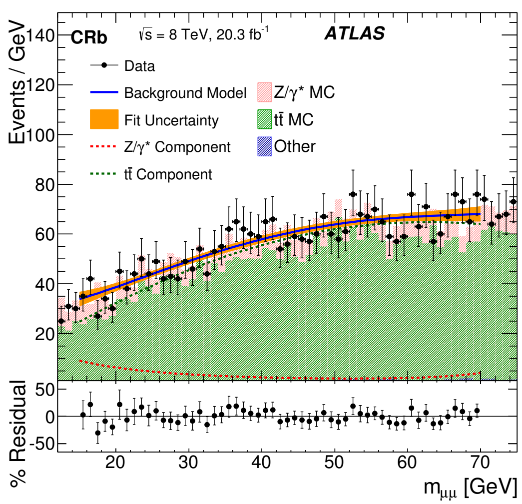


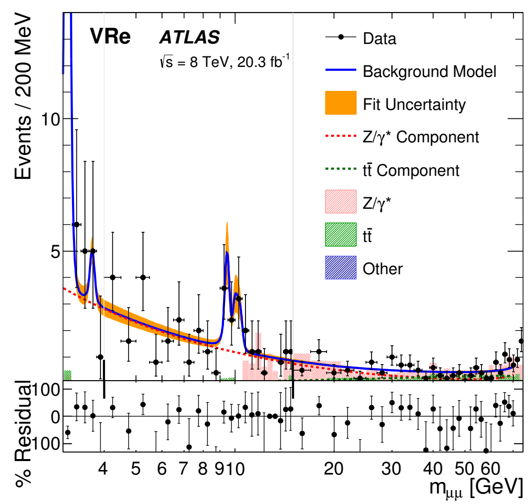



CRj
√s = 8 TeV, 20.3 fb-1
ATLAS
Background Model
Fit Uncertainty
Z/γ* Component
tt̄ Component
Data
Z/γ* MC
tt̄ MC
Other
Events / GeV
% Residual
mμμ [GeV]

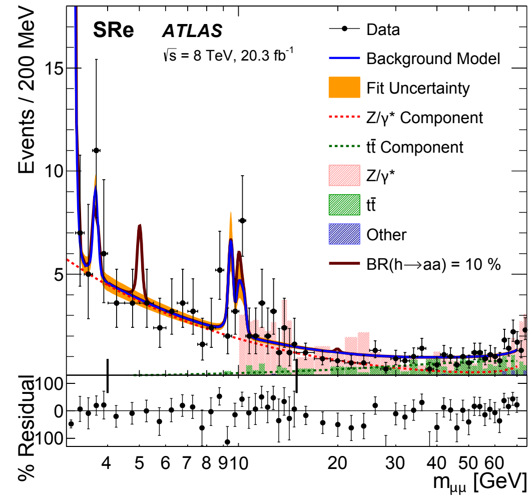

VRμ
ATLAS
√s = 8 TeV, 20.3 fb-1
Data
Background Model
Fit Uncertainty
Z/γ* Component
tt̄ Component
Z/γ*
tt̄
Other
Events / 200 MeV
% Residual
mμμ [GeV]


Signal MC
Best Fit
Fit ± 1σ Syst.
√s = 8 TeV
ATLAS Simulation
SRμ, ma = 5 GeV, mH = mh = 125 GeV
Event / 50 MeV
% Residual
mμμ [GeV]

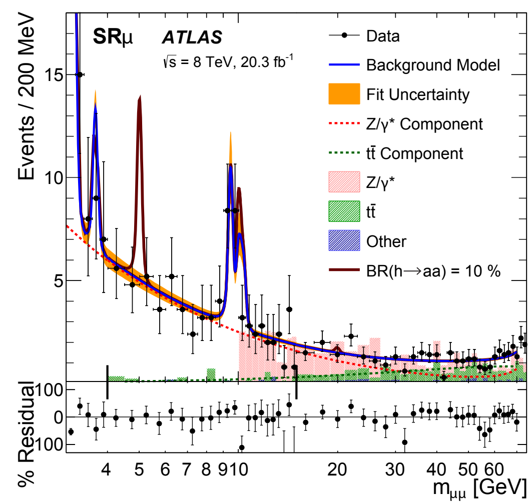

CRb
√s = 8 TeV, 20.3 fb-1
ATLAS
Data
Background Model
Fit Uncertainty
Z/γ* Component
tt̄ Component
Z/γ* MC
tt̄ MC
Other
Events / GeV
% Residual
mμμ [GeV]

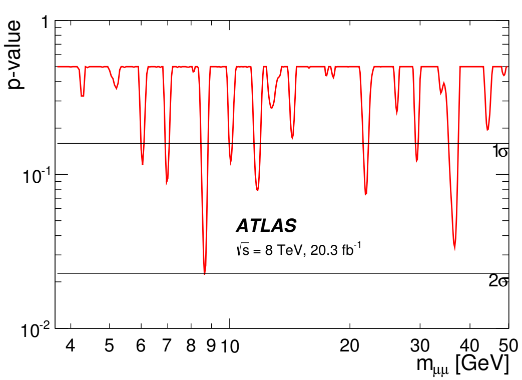

VRe
ATLAS
√s = 8 TeV, 20.3 fb-1
Data
Background Model
Fit Uncertainty
Z/γ* Component
tt̄ Component
Z/γ*
tt̄
Other
Events / 200 MeV
% Residual
mμμ [GeV]

Parameter	$f_{\Upsilon}\left[\frac{\Upsilon}{\psi+\Upsilon}\right]$ (%)	$f_{\text{Res}}\left[\frac{\psi+\Upsilon}{\text{Total}}\right]$ (%)	$f_{t\bar{t}}\left[\frac{t\bar{t}}{\text{Total}}\right]$ (%)
CRj	32.6±0.3	14.7±0.1	6.1±0.9
CRb	N/A	N/A	87.2±5.1
VRμ	35.8±6.0	18.8±2.3	28.2±3.2
VRe	36.3±9.2	12.2±2.3	34.2±3.6
SRμ	25.8±4.9	15.2±1.6	20.4±4.1
SRe	24.5±6.6	11.8±1.6	23.5±5.0



Par.	Value	Par.	Value
a_{μ}	$(99.86 \pm 0.01)\%$	$\sigma_{t\bar{t}}$	(60.7 ± 3.8) GeV
a_{σ}	$(1.68 \pm 0.02)\%$	$f_Z\left[\frac{Z}{\gamma^*+Z}\right]$	$(23.4 \pm 0.5)\%$
α_{CB}	1.49±0.03	$f_{\psi'}\left[\frac{2S}{1S+2S}\right]$	$(6.3 \pm 0.3)\%$
α_{γ^*}	$(-31 \pm 3)\ \text{TeV}^{-1}$	$f_{\Upsilon_{3S}}\left[\frac{3S}{2S+3S}\right]$	$(46.8 \pm 1.4)\%$
n_{γ^*}	-0.75±0.02	$f_{\Upsilon_{2S}}\left[\frac{2S+3S}{1S+2S+3S}\right]$	$(49.9 \pm 0.6)\%$

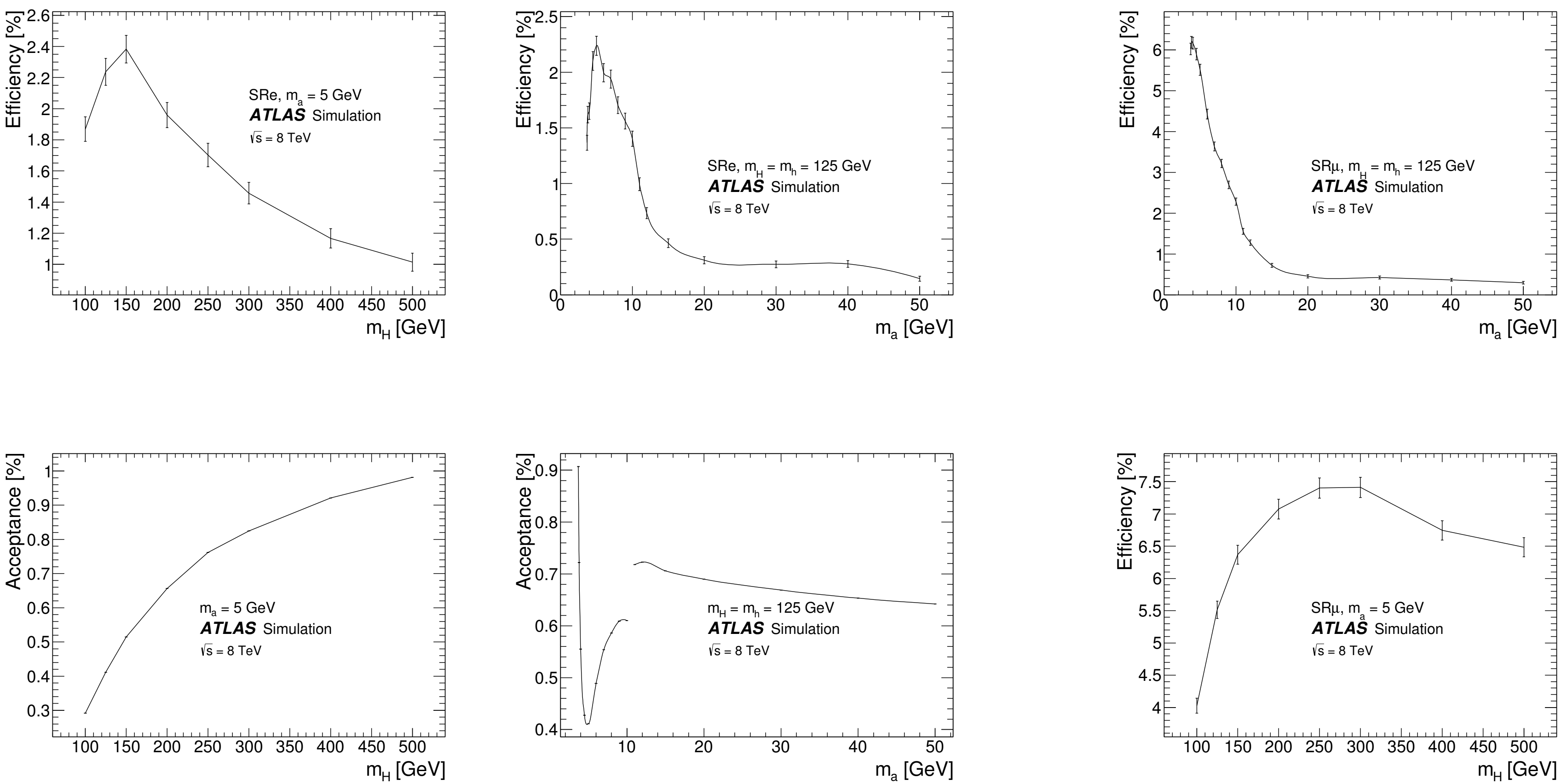


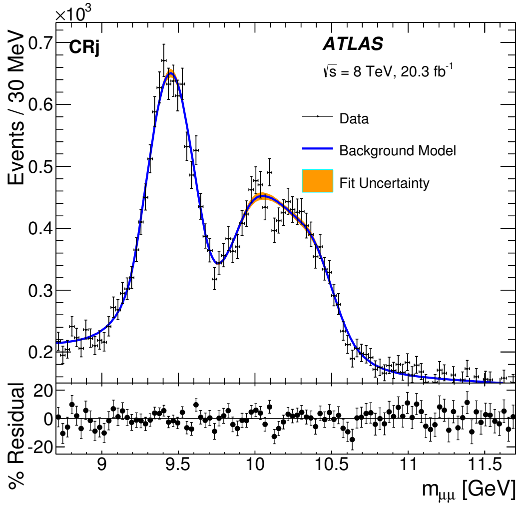


Selection	Relative efficiency (%)	
Generator-level	0.41±0.00	
Pass trigger	67.6±0.3	
Two selected muons	77.8±0.3	
Opposite charge (μ,μ)	100.0±0.0	
$p_{\text{T}}\ (\mu\mu) > 40$ GeV	98.1±0.1	
2.8 GeV $< m_{\mu\mu} <$ 70 GeV	100.0±0.0	
	SRμ (%)	SRe (%)
Third lepton	18.2±0.3	7.8±0.2
$\Delta\phi\ (\mu\mu,\ell)$	95.5±0.4	93.7±0.7
1,2 or 3 nearby tracks	91.4±0.5	82.8±1.1
Opposite charge (ℓ, lead-track)	91.2±0.9	88.1±1.1
Lepton isolation	75.5±0.9	84.6±1.3

ATLAS $h \to aa \to \mu\mu\tau\tau$

1505.01609




×10³
CRj
ATLAS
√s = 8 TeV, 20.3 fb⁻¹
Data
Background Model
Fit Uncertainty
Events / 30 MeV
% Residual
m_μμ [GeV]

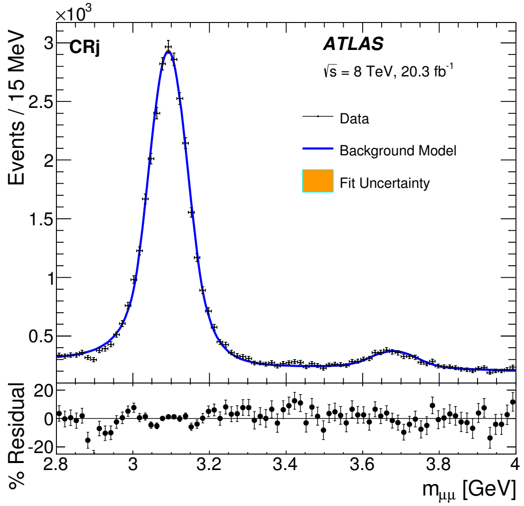

×10³
CRj
ATLAS
√s = 8 TeV, 20.3 fb⁻¹
Data
Background Model
Fit Uncertainty
Events / 15 MeV
% Residual
m_μμ [GeV]

Table 1: Event selection efficiencies $\epsilon_{\text{sim}}(m_{h_1}, m_{a_1})$ and $\epsilon_{\text{sim}}(m_{\gamma_D}, c\tau_{\gamma_D})$, as obtained from simulation, the geometric and kinematic acceptances $\alpha_{\text{gen}}(m_{h_1}, m_{a_1})$ and $\alpha_{\text{gen}}(m_{\gamma_D}, c\tau_{\gamma_D})$, calculated using only generator-level information, and their ratios (with statistical uncertainties), for a few representative NMSSM and dark SUSY benchmark samples. The experimental data-to-simulation scale factor ($\epsilon_{\text{data}}/\epsilon_{\text{sim}}$, described later) is not applied.

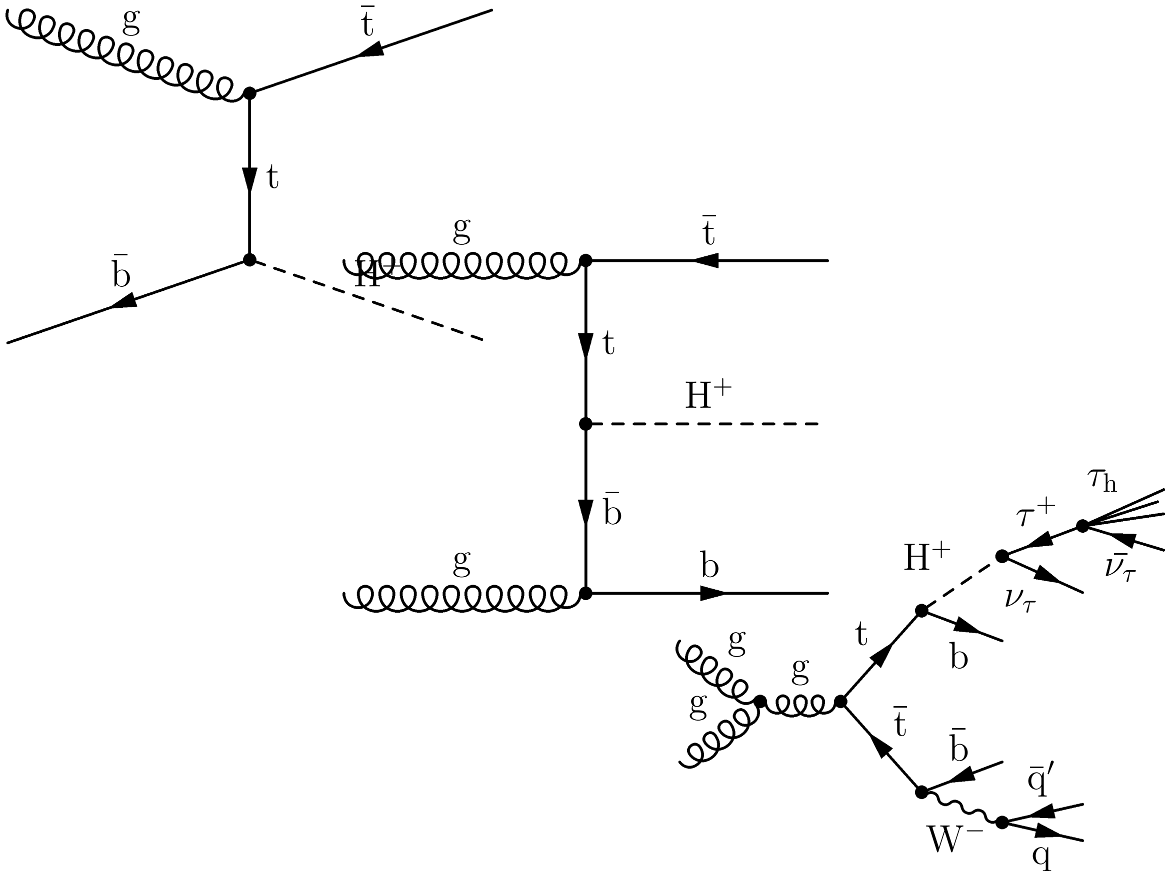
m_{h_1} [GeV]	90	125	125
m_{a_1} [GeV]	2	0.5	3.55
ϵ_{sim} [%]	11.0 ± 0.1	21.1 ± 0.1	17.3 ± 0.1
α_{gen} [%]	15.9 ± 0.1	32.0 ± 0.1	26.3 ± 0.1
$\epsilon_{\text{sim}}/\alpha_{\text{gen}}$	0.69 ± 0.01	0.66 ± 0.01	0.66 ± 0.01

m_{γ_D} [GeV]	0.25			1.0		
$c\tau_{\gamma_D}$ [mm]	0	0.5	2	0	0.5	2
ϵ_{sim} [%]	8.85 ± 0.12	1.76 ± 0.05	0.23 ± 0.03	6.13 ± 0.23	4.73 ± 0.07	1.15 ± 0.04
α_{gen} [%]	14.32 ± 0.14	2.7 ± 0.06	0.31 ± 0.03	8.89 ± 0.28	6.98 ± 0.09	1.68 ± 0.05
$\epsilon_{\text{sim}}/\alpha_{\text{gen}}$	0.62 ± 0.01	0.65 ± 0.02	0.74 ± 0.13	0.69 ± 0.03	0.68 ± 0.01	0.68 ± 0.03

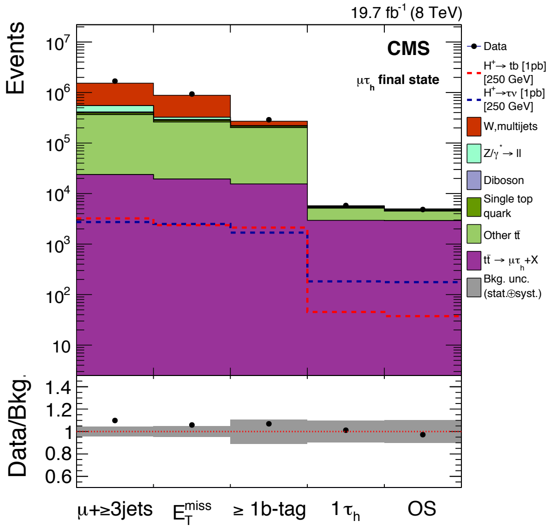
Scenarios

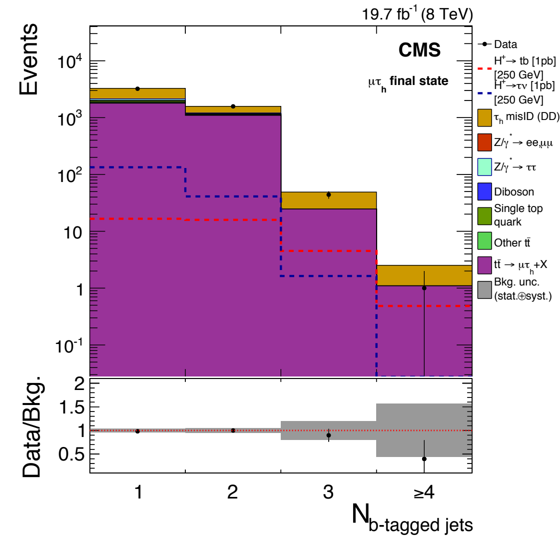
- mhmax: the mass of the lightest CP-even Higgs boson is maximized
- Interpret 125 GeV as lightest CP-even Higgs boson but drop maximal requirement: mhmod+ and mhmod-, differing in sign of mixing in stop sector

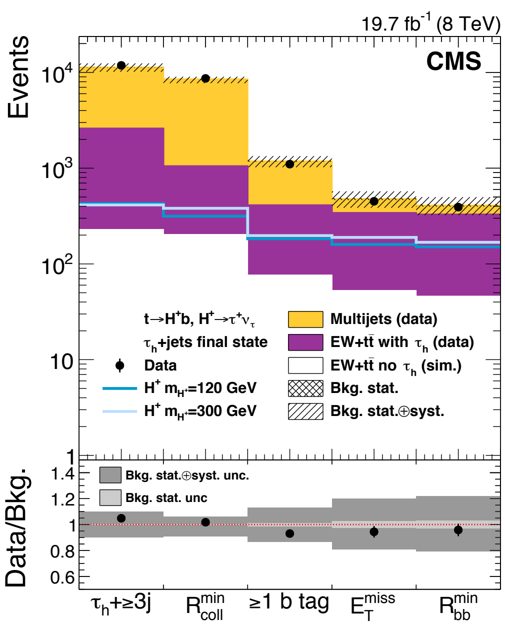
CMS search for charged Higgs bosons 1508.07774

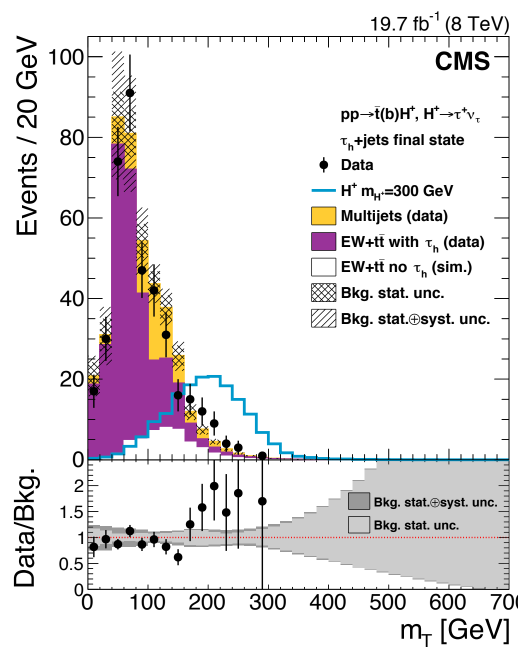


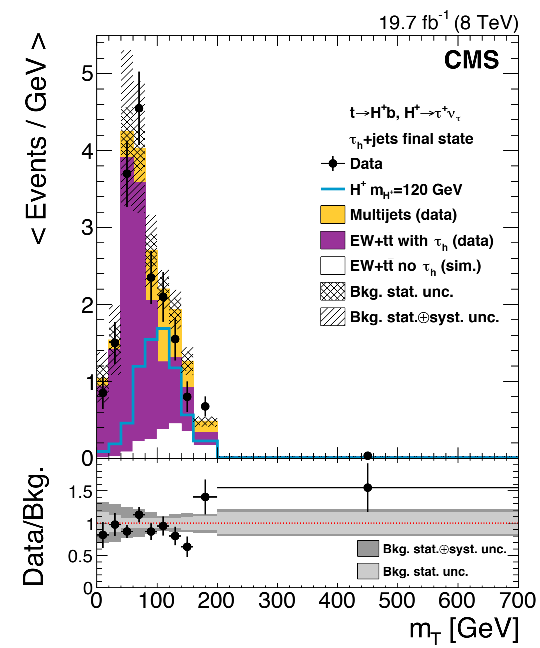
CMS search for charged Higgs bosons 1508.07774

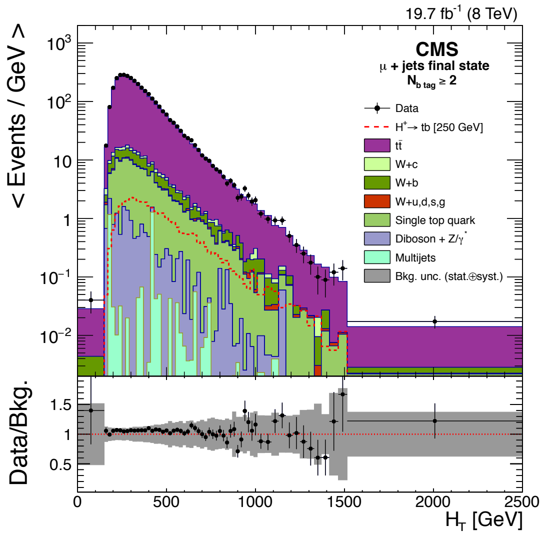


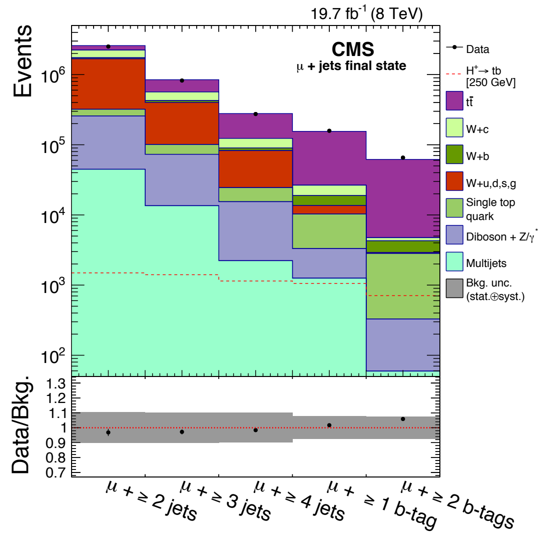


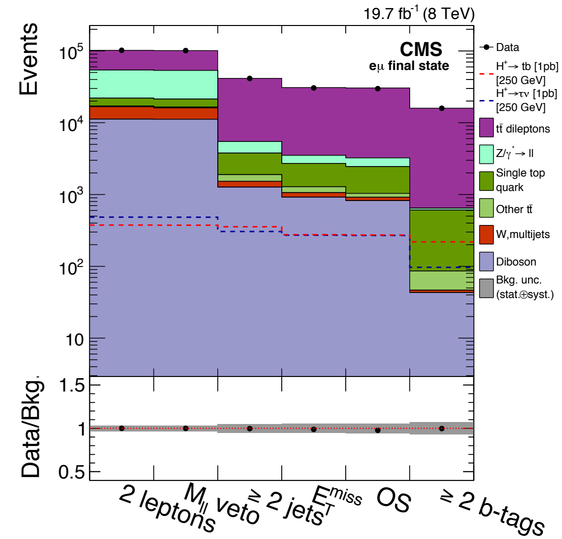


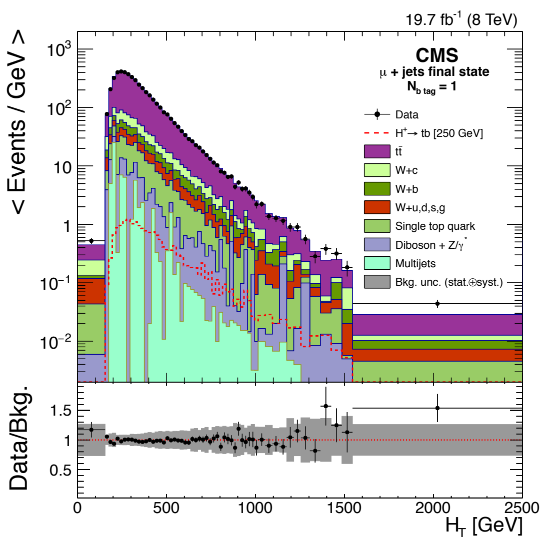


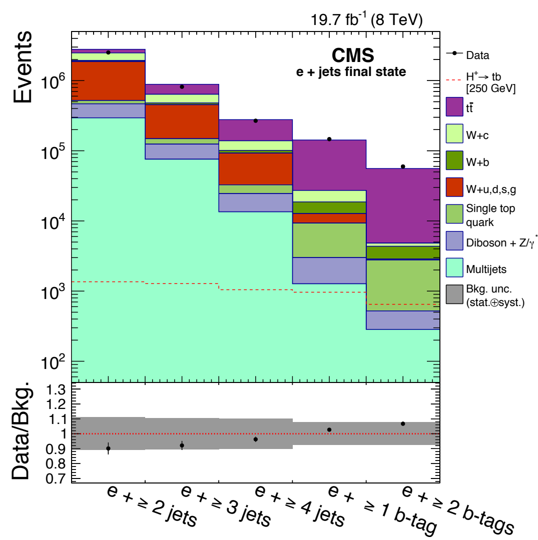


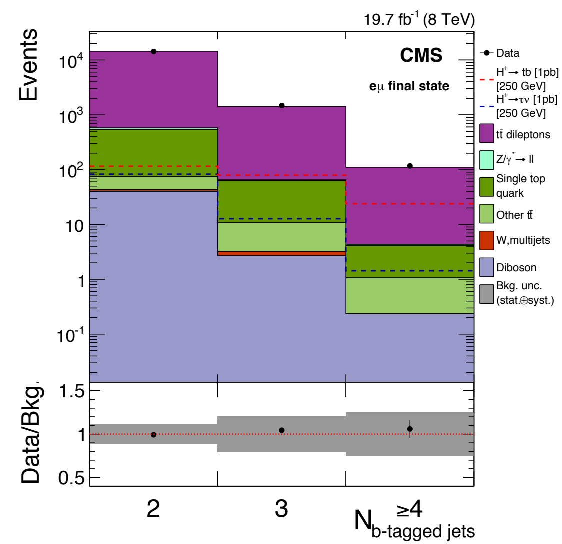

19.7 fb^-1 (8 TeV)
CMS
μ + jets final state
N_b tag ≥ 2
Data
H+→ tb [250 GeV]
tt̄
W+c
W+b
W+u,d,s,g
Single top quark
Diboson + Z/γ*
Multijets
Bkg. unc. (stat.⊕syst.)
< Events / GeV >
Data/Bkg.
H_T [GeV]


19.7 fb^-1 (8 TeV)
CMS
μ + jets final state
Data
H+→ tb [250 GeV]
tt̄
W+c
W+b
W+u,d,s,g
Single top quark
Diboson + Z/γ*
Multijets
Bkg. unc. (stat.⊕syst.)
Events
Data/Bkg.
μ + ≥ 2 jets
μ + ≥ 3 jets
μ + ≥ 4 jets
μ + ≥ 1 b-tag
μ + ≥ 2 b-tags

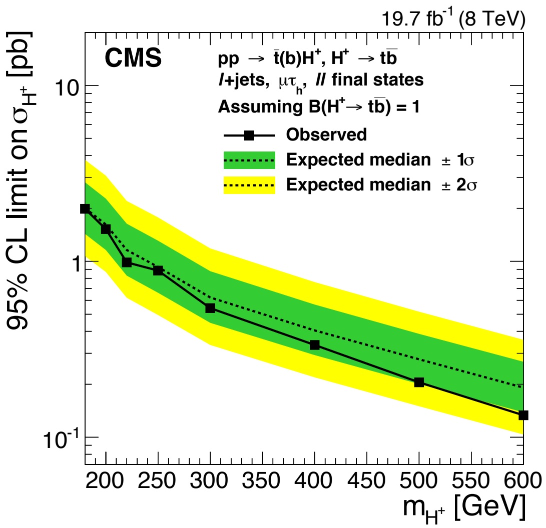

19.7 fb^-1 (8 TeV)
CMS
eμ final state
Data
H+→ tb [1pb] [250 GeV]
H+→τν [1pb] [250 GeV]
tt̄ dileptons
Z/γ*→ ll
Single top quark
Other tt̄
W,multijets
Diboson
Bkg. unc. (stat.⊕syst.)
Events
Data/Bkg.
2 leptons
M_ll veto
≥ 2 jets
E_T^miss
OS
≥ 2 b-tags

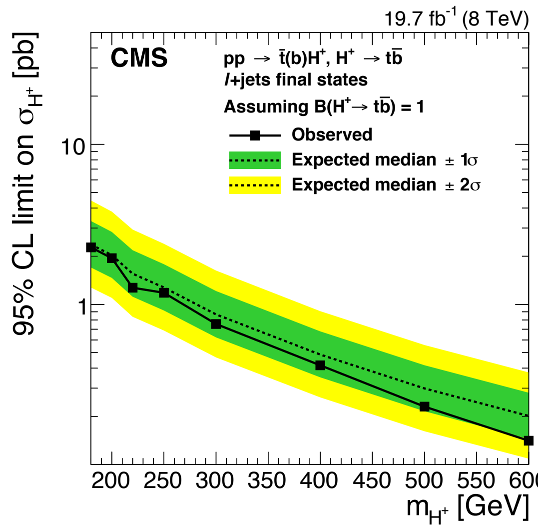

19.7 fb^-1 (8 TeV)
CMS
μ + jets final state
N_b tag = 1
Data
H+→ tb [250 GeV]
tt̄
W+c
W+b
W+u,d,s,g
Single top quark
Diboson + Z/γ*
Multijets
Bkg. unc. (stat.⊕syst.)
< Events / GeV >
Data/Bkg.
H_T [GeV]

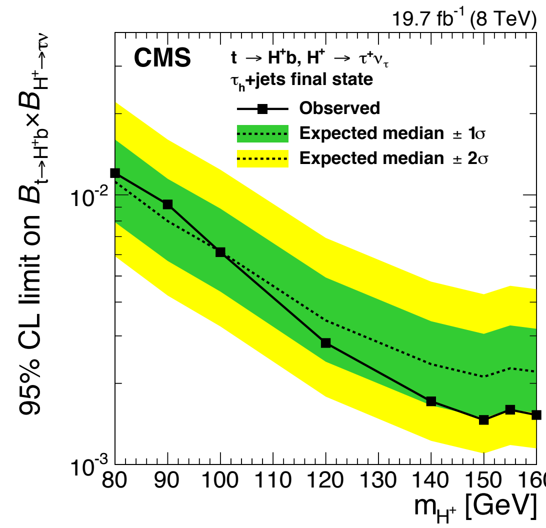

19.7 fb^-1 (8 TeV)
CMS
e + jets final state
Data
H+→ tb [250 GeV]
tt̄
W+c
W+b
W+u,d,s,g
Single top quark
Diboson + Z/γ*
Multijets
Bkg. unc. (stat.⊕syst.)
Events
Data/Bkg.
e + ≥ 2 jets
e + ≥ 3 jets
e + ≥ 4 jets
e + ≥ 1 b-tag
e + ≥ 2 b-tags

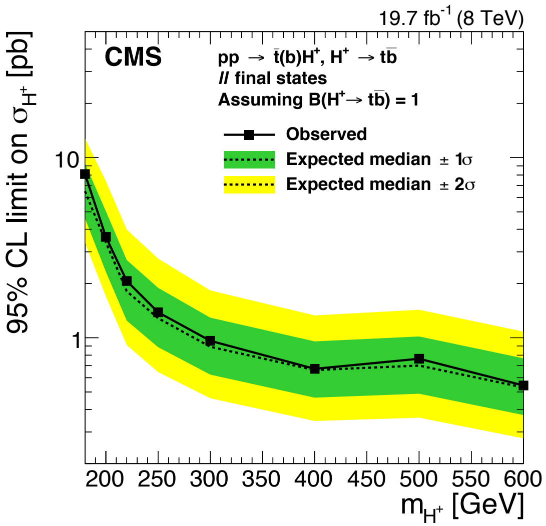

19.7 fb^-1 (8 TeV)
CMS
eμ final state
Data
H+→ tb [1pb] [250 GeV]
H+→τν [1pb] [250 GeV]
tt̄ dileptons
Z/γ*→ ll
Single top quark
Other tt̄
W,multijets
Diboson
Bkg. unc. (stat.⊕syst.)
Events
Data/Bkg.
N_b-tagged jets

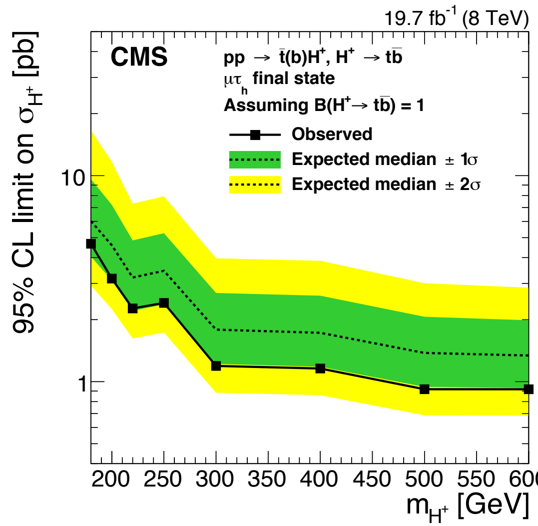
CMS search for charged Higgs bosons 1508.07774

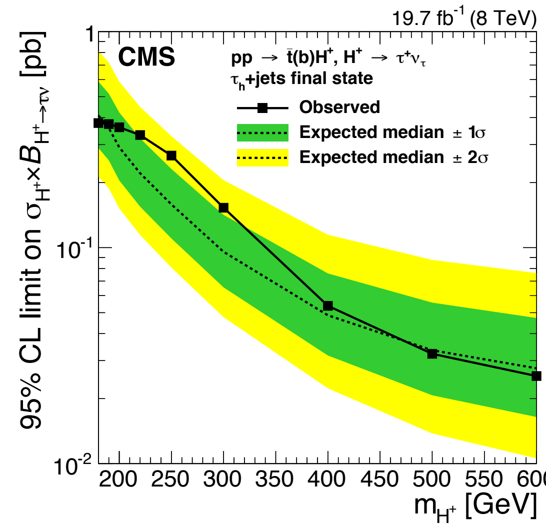


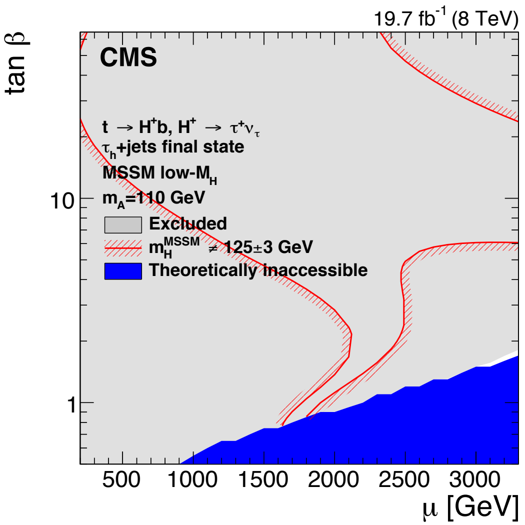




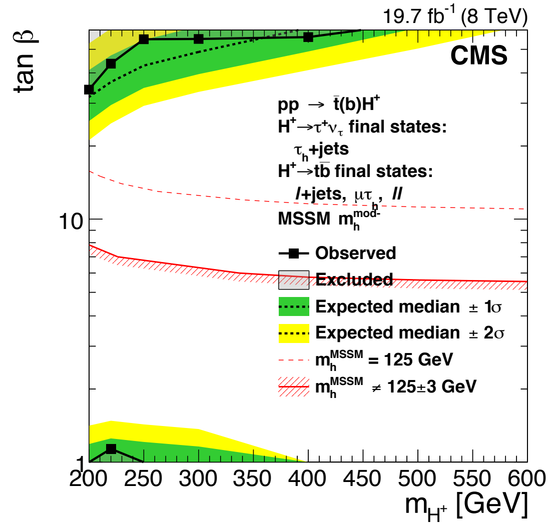




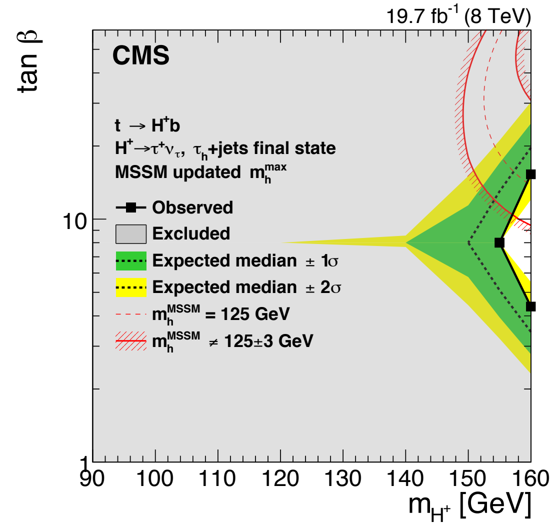




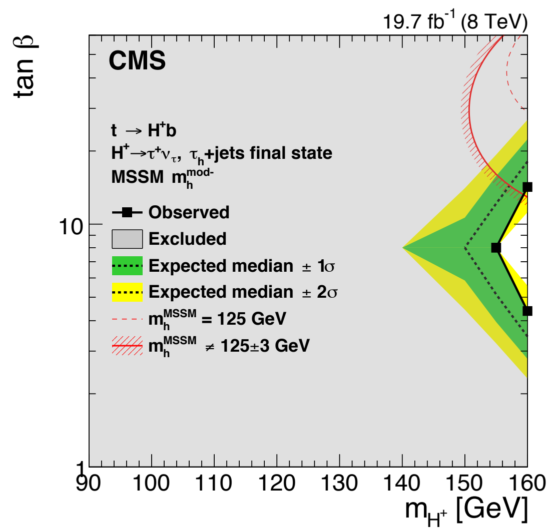
19.7 fb-1 (8 TeV)
CMS
t → H+b, H+ → τ+ντ
τh+jets final state
MSSM low-MH
mA=110 GeV
Excluded
mHMSSM ≠ 125±3 GeV
Theoretically inaccessible
tan β
μ [GeV]



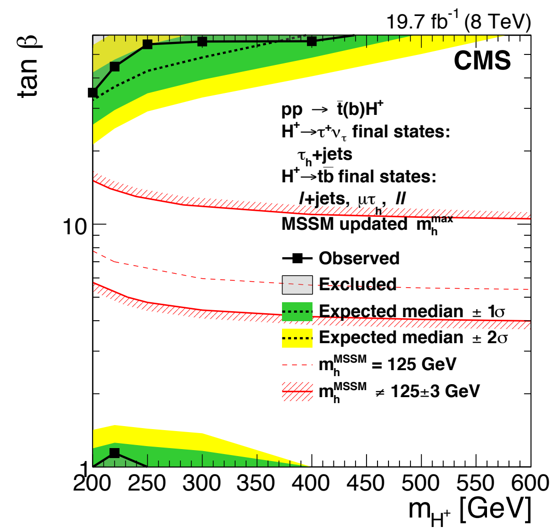
19.7 fb-1 (8 TeV)
CMS
pp → t̄(b)H+
H+→τ+ντ final states:
τh+jets
H+→tb̄ final states:
l+jets, μτh, ll
MSSM mhmod-
Observed
Excluded
Expected median ± 1σ
Expected median ± 2σ
mhMSSM = 125 GeV
mhMSSM ≠ 125±3 GeV
tan β
mH+ [GeV]



19.7 fb-1 (8 TeV)
CMS
t → H+b
H+→τ+ντ, τh+jets final state
MSSM updated mhmax
Observed
Excluded
Expected median ± 1σ
Expected median ± 2σ
mhMSSM = 125 GeV
mhMSSM ≠ 125±3 GeV
tan β
mH+ [GeV]



19.7 fb-1 (8 TeV)
CMS
t → H+b
H+→τ+ντ, τh+jets final state
MSSM mhmod-
Observed
Excluded
Expected median ± 1σ
Expected median ± 2σ
mhMSSM = 125 GeV
mhMSSM ≠ 125±3 GeV
tan β
mH+ [GeV]



19.7 fb-1 (8 TeV)
CMS
pp → t̄(b)H+
H+→τ+ντ final states:
τh+jets
H+→tb̄ final states:
l+jets, μτh, ll
MSSM updated mhmax
Observed
Excluded
Expected median ± 1σ
Expected median ± 2σ
mhMSSM = 125 GeV
mhMSSM ≠ 125±3 GeV
tan β
mH+ [GeV]

	$H^+ \to t\bar{b}$	$t\bar{t}$	W+c	W+b	W+u,d,s,g	single top quark	$Z/\gamma^*/VV$	Multijets
Single-e trigger	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Single-μ trigger	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
e identification	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
μ identification	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Jet energy scale (S)	4.0	6.4	15	11	14	9.2	27	49
Jet energy resolution (S)	0.1	0.3	1.7	2.3	1.4	0.8	2.3	6.9
b tagging (S)	3.9	1.3	14	6.2	11	0.7	5.4	16
Top quark p_T modelling (S)		3.5						
Pileup modelling (S)	1.2	0.7	2.3	0.5	0.4	0.7	3.7	7.0
Normalization from data, e+jets		5.5*	4.9*	25*	9.6*			
Normalization from data, μ+jets		5.2*	10*	34*	10*			
Cross section						8.0	50	100
Fact./renorm. scales (S)		7.3						
Q^2 scale (S)		7.6						
Integrated Luminosity	2.6					2.6	2.6	2.6

	Signal H^+H^-	Signal H^+W^-	Signal H^+	Multi-jets	EW+$t\bar{t}$ with τ_h	EW+$t\bar{t}$ no τ_h
τ part of trigger; data	1.5–1.8	1.3–1.5	1.8–3.0	−0.5	1.2	1.4
τ part of trigger; simulation	0.7–0.8	0.6–0.7	0.8–1.1	−0.2		0.8
E_T^{miss} part of trigger; data	2.6–3.3	2.5–2.8	2.9–4.2	−1.2	2.5	2.8
E_T^{miss} part of trigger; simulation	0.1	0.1	0.1	−0.1		0.4
Approximation in E_T^{miss} part of trigger					12	
Single μ trigger; data					−0.1	
Veto of events with e	0.1–0.2	0.2–0.3	0.2–0.3	<−0.1		0.4
Veto of events with μ	0.1	0.1–0.2	0.1	<−0.1		0.5
τ_h identification (S)	6.0	6.0	5.9–6.0	−0.8	6.0	
e misidentification as τ_h (S)	<0.1	<0.1	<0.1	−0.1		3.3
μ misidentification as τ_h (S)	<0.1	<0.1	<0.1	<−0.1		1.1
Jet misidentification as τ_h (S)	0.1	0.1–0.3	0.1	−6.9		17
τ_h energy scale (S)	0.3–2.6	2.7–5.2	0.3–2.7	−1.8	5.8	2.0
Jet energy scale	2.6–5.2	2.0–3.0	1.6–2.1	−1.4		3.2
Jet energy resolution	1.1–1.8	0.5–1.3	0.7–1.5	−0.2		3.2
Unclustered E_T^{miss} energy scale	0.1–0.4	0.1–0.9	0.1–0.4	−0.5		1.5
b-jet tagging (S)	5.9–20	4.7–5.3	4.6–5.4	−3.5		5.0
Top quark p_T modelling (S)				$^{+5.6}_{-6.8}$		$^{+11}_{-6.6}$
Pileup modelling	0.1–0.9	0.1–0.8	0.1–0.6	−0.1		2.9
μ identification; data					<−0.1	
Multijet contamination					2.0	
$W \to \tau\nu_\tau \to \mu\nu_\mu\nu_\tau$ fraction					1.2	
Non-emb. vs. emb. difference (S)					$^{+14}_{-12}$	
Multijet m_T distribution shape (S)				4.6		
Multijet template fit				3.0		
Probabilistic m_T in single top quark						6.8
$t\bar{t}$ cross section, scale	$^{+2.5}_{-3.4}$	$^{+2.5}_{-3.4}$		$^{+1.0}_{-0.7}$		$^{+2.2}_{-2.9}$
$t\bar{t}$ cross section, PDF+α_S	4.6	4.6		−1.6		4.0
Single top quark cross section						1.0
W+jets, Z/γ^*, VV cross section						0.1
Integrated luminosity	2.6	2.6	2.6	−0.8		2.6

	Signal	$t\bar{t} \to \mu\tau_h + X$	$t\bar{t}$ dilepton	τ_h mis-id	single top quark
Single μ trigger	2.0	2.0	2.0		
e identification	2.0	2.0	2.0		2.0
μ identification	1.0	1.0	1.0		1.0
τ_h identification	6.0	6.0			6.0
e misidentification as τ_h			3.0		
μ misidentification as τ_h			3.0		
Jet misidentification as τ_h			20		
τ_h energy scale (S)	0.6	2.4	4.4		4.1
Jet energy scale (S)	2.5	1.9	2.6		3.9
Jet energy resolution (S)	0.8	0.1	1.6		0.2
Unclustered E_T^{miss} energy scale (S)	0.8	0.1	1.8		0.2
b tagging (S)	1.8	1.8	2.7		3.2
udsg→b mistagging (S)	<0.1	<0.1	<0.1		0.1
Top quark p_T modelling (S)		5.4	5.2		
Pileup modelling	4.0	2.0	8.0		2.0
Misidentified τ_h background				11	
Cross sections		$^{+2.5}_{-3.4} \pm 4.6$	$^{+2.5}_{-3.4} \pm 4.6$		8.0
Matching scale (S)		12	5.1		
Fact./renorm. scale (S)		3.4	7.5		
PDF effect on shape		shape only	shape only		
Heavy flavours (S)		<0.1	<0.1		
Integrated luminosity	2.6	2.6	2.6		2.6

Source	N_{events} (± stat ± syst)
$H^+ \to \tau^+\nu_\tau$, $m_{H^+} = 250$ GeV	$176 \pm 10 \pm 13$
$H^+ \to t\bar{b}$, $m_{H^+} = 250$ GeV	$37 \pm 2 \pm 3$
$t\bar{t} \to \mu\tau_h + X$	$2913 \pm 14 \pm 242$
Misidentified τ_h	$1544 \pm 14 \pm 175$
$t\bar{t}$ dilepton	$101 \pm 10 \pm 27$
$Z/\gamma^* \to ee, \mu\mu$	$12 \pm 3 \pm 4$
$Z/\gamma^* \to \tau\tau$	$162 \pm 40 \pm 162$
Single top quark	$150 \pm 12 \pm 18$
Dibosons	$20 \pm 3 \pm 2$
Total SM backgrounds	$4903 \pm 45 \pm 341$
Data	4839

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

	Signal	$t\bar{t}$ dilepton	$Z/\gamma^* \to \ell\ell$	single top quark
$e\mu$ trigger efficiency	3.0	3.0	3.0	3.0
e identification	2.0	2.0	2.0	2.0
μ identification	1.0	1.0	1.0	1.0
Jet energy scale (S)	1.4	1.1	1.7	1.4
Jet energy resolution (S)	0.3	0.3	0.4	0.4
Unclustered E_T^{miss} energy scale (S)	1.3	2.1	11.7	2.6
b tagging (S)	2.4	3.7	10	4.3
udsg→b mistagging (S)	2.3	3.6	10	4.4
Top quark p_T modelling (S)		3.8		
Pileup modelling	0.6	0.4	1.2	1.2
Cross sections		$^{+2.5}_{-3.4} \pm 4.6$	4.0	8.0
Matching scale (S)		7.7		
Fact./renorm. scale (S)		8.4		
PDF shape		shape only		
Heavy flavours (S)		<0.1		
Integrated luminosity	2.6	2.6	2.6	2.6

	$N_{events}(\pm \text{stat} \pm \text{syst})$
Signal, $m_{H^+} = 120$ GeV	$151 \pm 4 ^{+17}_{-18}$
Signal, $m_{H^+} = 300$ GeV	$168 \pm 2 \pm 16$
EW+$t\bar{t}$ with τ_h (data)	$283 \pm 12 ^{+55}_{-54}$
Multijet background (data)	$80 \pm 3 ^{+9}_{-10}$
EW+$t\bar{t}$ no τ_h (sim.)	$47 \pm 2 ^{+11}_{-10}$
Total expected	$410 \pm 12 ^{+57}_{-56}$
Data	392

m_{H^+} [GeV]	Expected limit [pb] -2σ	-1σ	median	$+1\sigma$	$+2\sigma$	Observed limit [pb] limit
95% CL upper limit on $\sigma(pp \to \bar{t}(b)H^+)$ with $\mathcal{B}(H^+ \to t\bar{b}) = 1$						
180	1.07	1.43	2.01	2.81	3.78	1.99
200	0.87	1.16	1.62	2.27	3.07	1.52
220	0.62	0.83	1.16	1.64	2.20	0.99
250	0.49	0.66	0.93	1.31	1.78	0.89
300	0.33	0.45	0.62	0.88	1.18	0.54
400	0.22	0.29	0.40	0.57	0.76	0.33
500	0.15	0.20	0.28	0.39	0.52	0.21
600	0.10	0.14	0.19	0.27	0.36	0.13

m_{H^+} [GeV]	Expected limit -2σ	-1σ	median	$+1\sigma$	$+2\sigma$	Observed limit
95% CL upper limit on $\mathcal{B}(t \to H^+b)\,\mathcal{B}(H^+ \to \tau^+\nu_\tau)$						
80	0.0059	0.0079	0.0112	0.0160	0.0221	0.0120
90	0.0042	0.0057	0.0080	0.0115	0.0160	0.0092
100	0.0033	0.0044	0.0062	0.0089	0.0124	0.0061
120	0.0018	0.0024	0.0034	0.0049	0.0069	0.0028
140	0.0012	0.0017	0.0024	0.0034	0.0048	0.0017
150	0.0011	0.0015	0.0021	0.0031	0.0043	0.0015
155	0.0012	0.0016	0.0023	0.0033	0.0046	0.0016
160	0.0011	0.0016	0.0022	0.0032	0.0045	0.0015
95% CL upper limit on $\sigma(pp \to \bar{t}(b)H^+)\,\mathcal{B}(H^+ \to \tau^+\nu_\tau)$ [pb]						
180	0.213	0.289	0.409	0.587	0.816	0.377
190	0.188	0.254	0.358	0.516	0.719	0.373
200	0.152	0.205	0.291	0.423	0.587	0.361
220	0.114	0.155	0.221	0.321	0.448	0.332
250	0.081	0.110	0.159	0.231	0.328	0.267
300	0.048	0.065	0.096	0.142	0.205	0.153
400	0.022	0.032	0.049	0.076	0.115	0.054
500	0.014	0.021	0.033	0.056	0.088	0.032
600	0.011	0.016	0.028	0.047	0.076	0.025

Source	ee	eμ	μμ
$H^+ \to \tau^+\nu_\tau$, $m_{H^+} = 250$ GeV	$39 \pm 3 \pm 3$	$97 \pm 4 \pm 5$	$40 \pm 3 \pm 3$
$H^+ \to t\bar{b}$, $m_{H^+} = 250$ GeV	$85 \pm 3 \pm 2$	$219 \pm 5 \pm 5$	$90 \pm 3 \pm 2$
$t\bar{t}$ dilepton	$5692 \pm 17 \pm 520$	$15296 \pm 28 \pm 1364$	$6332 \pm 18 \pm 572$
Other $t\bar{t}$	$22 \pm 4 \pm 5$	$40 \pm 5 \pm 9$	$17 \pm 3 \pm 5$
$Z/\gamma^* \to \ell\ell$	$96 \pm 7 \pm 35$	$36 \pm 2 \pm 7$	$139 \pm 10 \pm 42$
W+jets, multijets	$6 \pm 2 \pm 1$	$3 \pm 1 \pm 1$	< 1
Single top quark	$199 \pm 10 \pm 21$	$522 \pm 15 \pm 54$	$228 \pm 10 \pm 26$
Dibosons	$15 \pm 1 \pm 2$	$43 \pm 2 \pm 6$	$20 \pm 1 \pm 3$
Total SM backgrounds	$6032 \pm 20 \pm 521$	$15941 \pm 32 \pm 1365$	$6736 \pm 23 \pm 575$
Data	6162	15902	6955

Source	$N_{b\,tag} = 1$	$N_{b\,tag} \geq 2$	$N_{b\,tag} = 1$	$N_{b\,tag} \geq 2$
	e+jets		μ+jets	
$H^+ \to t\bar{b}$, $m_{H^+} = 250$ GeV	$315 \pm 4 \pm 17$	$647 \pm 6 \pm 34$	$348 \pm 5 \pm 19$	$707 \pm 7 \pm 37$
$t\bar{t}$	$64111 \pm 74 \pm 5174$	$51059 \pm 66 \pm 4679$	$71593 \pm 78 \pm 5711$	$57094 \pm 70 \pm 5160$
W+c	$8031 \pm 89 \pm 1047$	$482 \pm 21 \pm 79$	$7156 \pm 77 \pm 11193$	$460 \pm 18 \pm 92$
W+b	$4470 \pm 61 \pm 1206$	$1486 \pm 35 \pm 404$	$3926 \pm 53 \pm 1386$	$1364 \pm 32 \pm 484$
W+u,d,s,g	$3326 \pm 44 \pm 598$	$90 \pm 7 \pm 21$	$3231 \pm 39 \pm 581$	$95 \pm 7 \pm 22$
Single top quark	$4059 \pm 42 \pm 463$	$2253 \pm 30 \pm 274$	$4496 \pm 44 \pm 524$	$2493 \pm 32 \pm 295$
$Z/\gamma^*/VV$	$1492 \pm 54 \pm 771$	$237 \pm 21 \pm 130$	$1792 \pm 60 \pm 942$	$269 \pm 22 \pm 140$
Multijet background	$990 \pm 270 \pm 1040$	$280 \pm 160 \pm 290$	$1220 \pm 480 \pm 1260$	$59 \pm 34 \pm 60$
Total SM backgrounds	$86480 \pm 310 \pm 5620$	$55890 \pm 190 \pm 4720$	$93410 \pm 500 \pm 6240$	$61836 \pm 95 \pm 5194$
Data	86580	59637	92391	65472