Searches for Higgs Bosons decaying into Fermions with the ATLAS Detector

$H \to \tau\tau$, $H \to bb$, $H \to \mu\mu$

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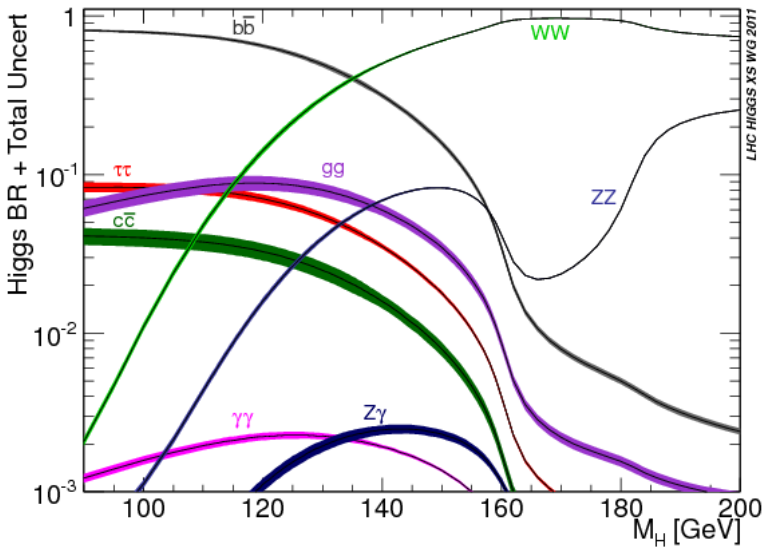
FSP 101 ATLAS

Emmy Noether-Programm
Deutsche Forschungsgemeinschaft DFG

Julian Glatzer
on behalf of the ATLAS collaboration

April 12, 2012

Overview



arXiv:1101.0593

Standard Model:

$H \rightarrow \tau\tau$

$VH, H \rightarrow bb$

Beyond the Standard Model:

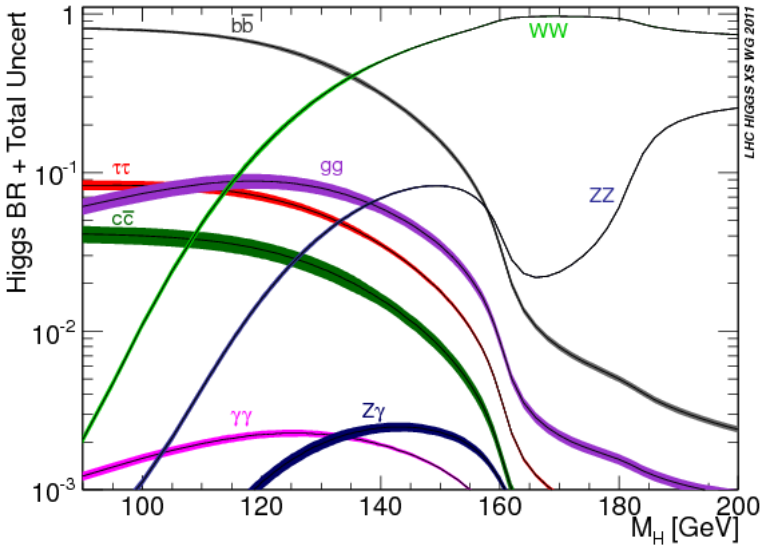
MSSM $h/A/H \rightarrow \tau\tau$

MSSM $H^{+} \rightarrow \tau\nu$

NMSSM $a_1 \rightarrow \mu\mu$

Standard Model

$H \rightarrow \tau\tau$



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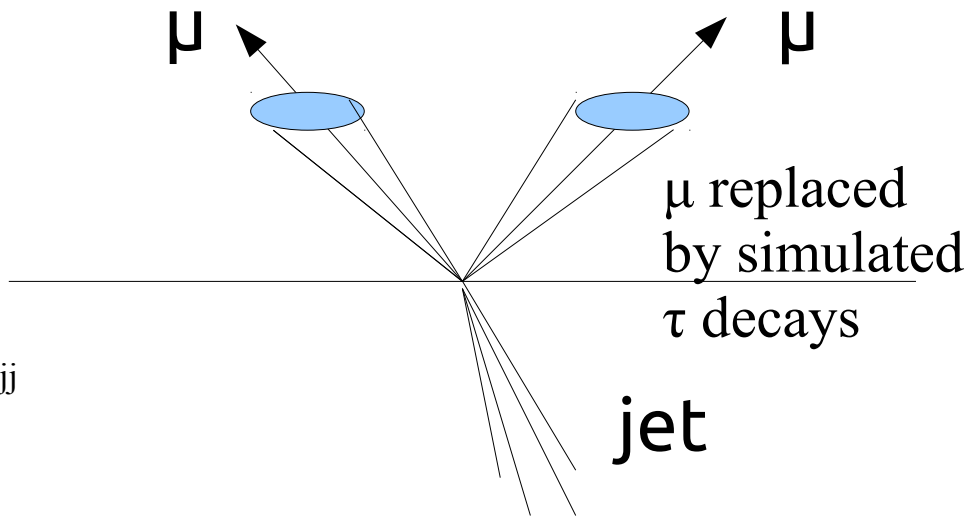
SM H→ττ: Analysis Channels

ee/eμ/μμ	$e\tau_h$,$\mu\tau_h$	$\tau_h\tau_h$

with several subchannels based on additional jets

- **Subchannels**
  - **0 jets**
  - **1 jet**: p_T, ($m_{\tau\tau j}$)
  - **VBF 2 jets**: p_T, $\Delta\eta$, m_{jj}, (CJV)
  - ll channel: **VH 2 jets**: p_T, $\Delta\eta$, m_{jj}
- **Background estimation**
  - Z+jets: τ-embedded Z→μμ
  - Multijet background from data
  - Misidentified τ decays: correction from data



Schematic representation of the embedding procedure

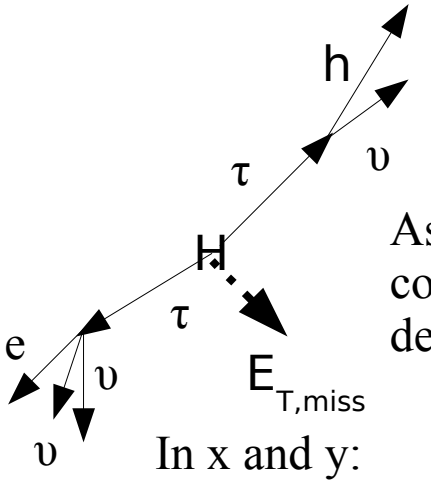
Mass Reconstruction

Effective mass

$$m_{\tau\tau}^{\text{effective}} = \sqrt{(p_e + p_\mu + p_{E_T^{miss}})^2}$$

$$p_{E_T^{miss}} = (E_T^{miss}, E_x^{miss}, E_y^{miss}, 0)$$

Collinear Mass



Assume neutrinos are collinear to visible decay products

In x and y:
Sum of neutrino momenta equal to $E_{T,miss}$
→ 2 equations, 2 unknowns

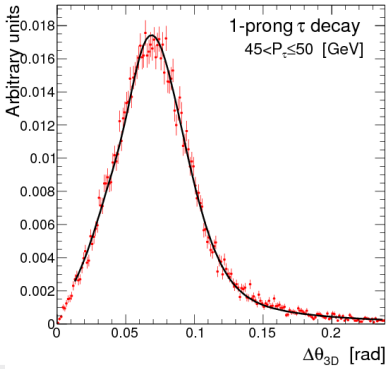
MMC Mass

Elagin et al., NIM A654 (2011) 481

Collinearity requirement relaxed
→ 7 unknowns,from neutrino 4 vector
→ 4 equations: 2x τ mass, $E_{x,miss}$ $E_{y,miss}$

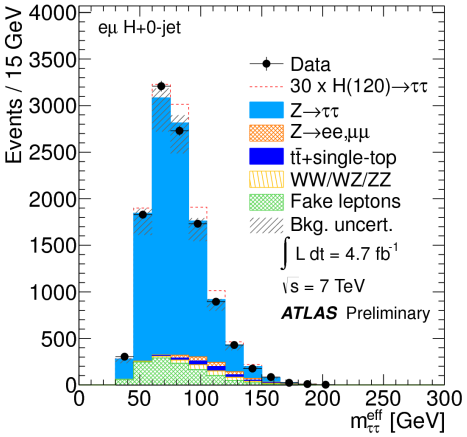
Scan over
- mass(υ,υ)
- $\Delta\varphi_1$(υ, h),
- $\Delta\varphi_2$(υ, l)

weight with PDF

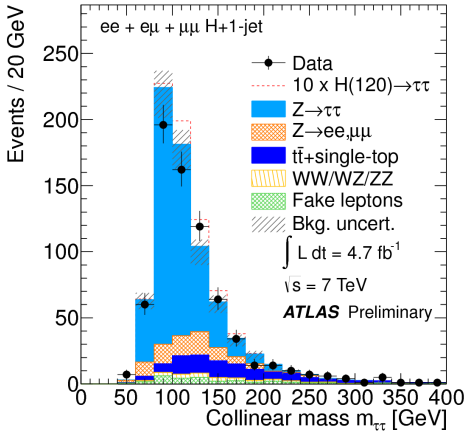


SM H→ττ: ll Channel

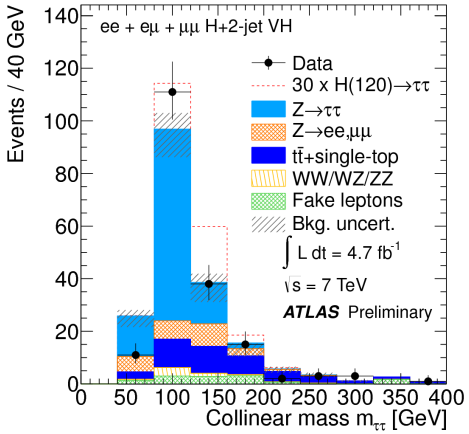
- **Subchannels**
  - **0 jets** eμ → effective mass
  - **1 jet** ee,μμ,eμ, p_T > 40 GeV, $m_{\tau\tau j}$>225 GeV
  - **VBF 2 jets** ee,μμ,eμ, p_T>40,25 GeV Δη>3, m_{jj}>350 GeV, central jet veto
  - **VH 2 jets**, ee,μμ,eμ, Δη<2, 50 GeV < m_{jj}<120 GeV
- **Background estimation**
  - Z+jets: τ-embedded Z→μμ
  - Fake lepton: template fit based on inverted lepton isolation



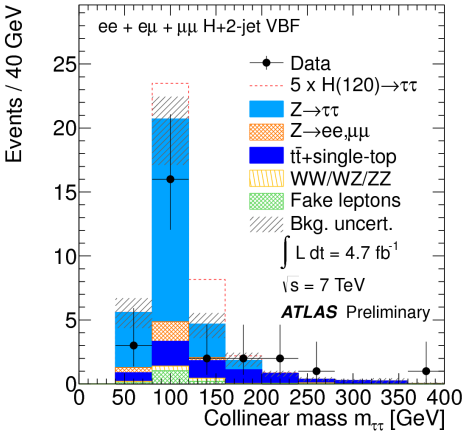
0 jets



1 jet



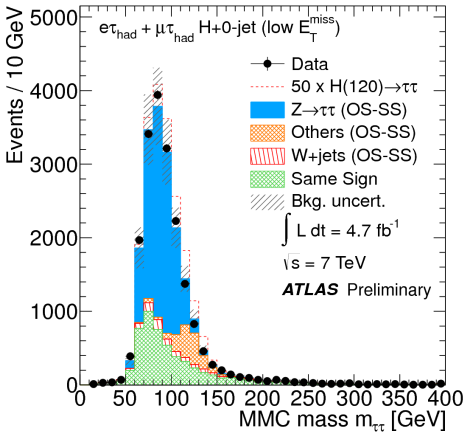
2 jets VBF



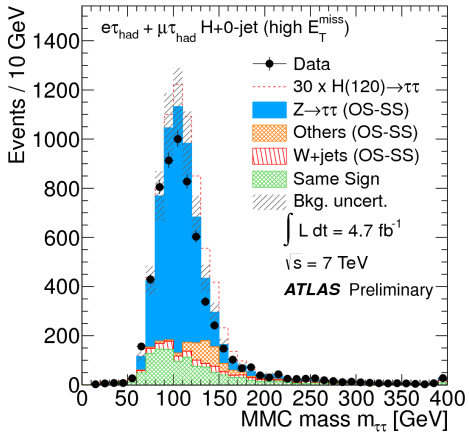
2 jets VH

SM H→ττ: lτ_h Channel

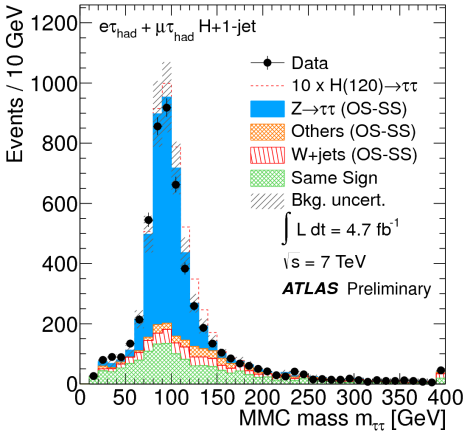
- **Subchannels**
  - **0 jets** with $E_{T,miss} > 20$ GeV and $E_{T,miss} < 20$ GeV
  - **1 jet**, $p_T > 20$ GeV
  - **VBF 2 jets** in opposite hemispheres, $m_{jj} > 300$ GeV
- **Background estimation**
  - Based on SS data
  - For all backgrounds, but multijet, #events(OS)-#events(SS) is added
  - For W background a correction for τ misidentification rates is derived in a high m_T region



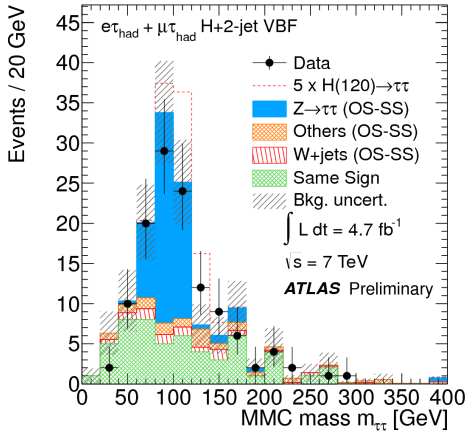
0 jets, low $E_{T,miss}$



0 jets, high $E_{T,miss}$



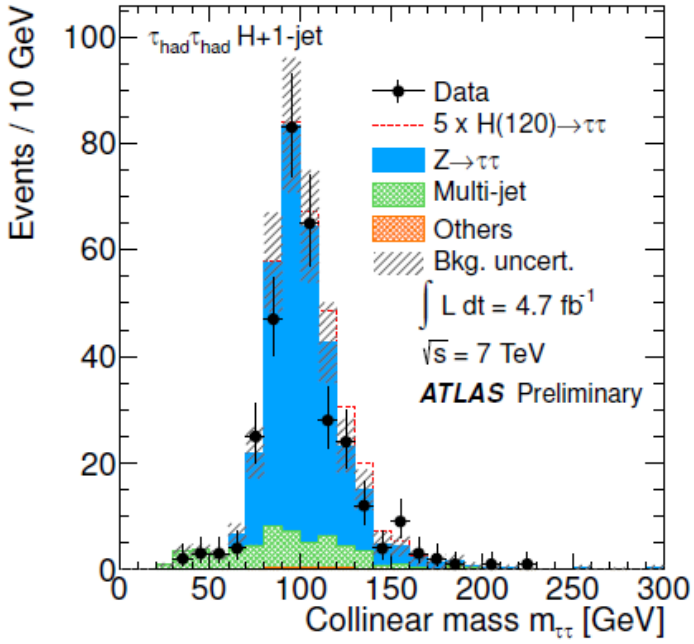
1 jet



2 jets VBF

SM H→ττ: $\tau_h \tau_h$ Channel

- **Preselection:** 2 τ_h trigger, τ_h p_T > 35/25 GeV
- **1 jet selection**
  - jet p_T > 40 GeV
  - $E_{T,miss}$ > 20 GeV
  - $\Delta R(\tau, \tau) < 2.2$
  - $m_{\tau\tau j}$ > 225 GeV
  - Physical solution of collinear mass
- **Background estimation**



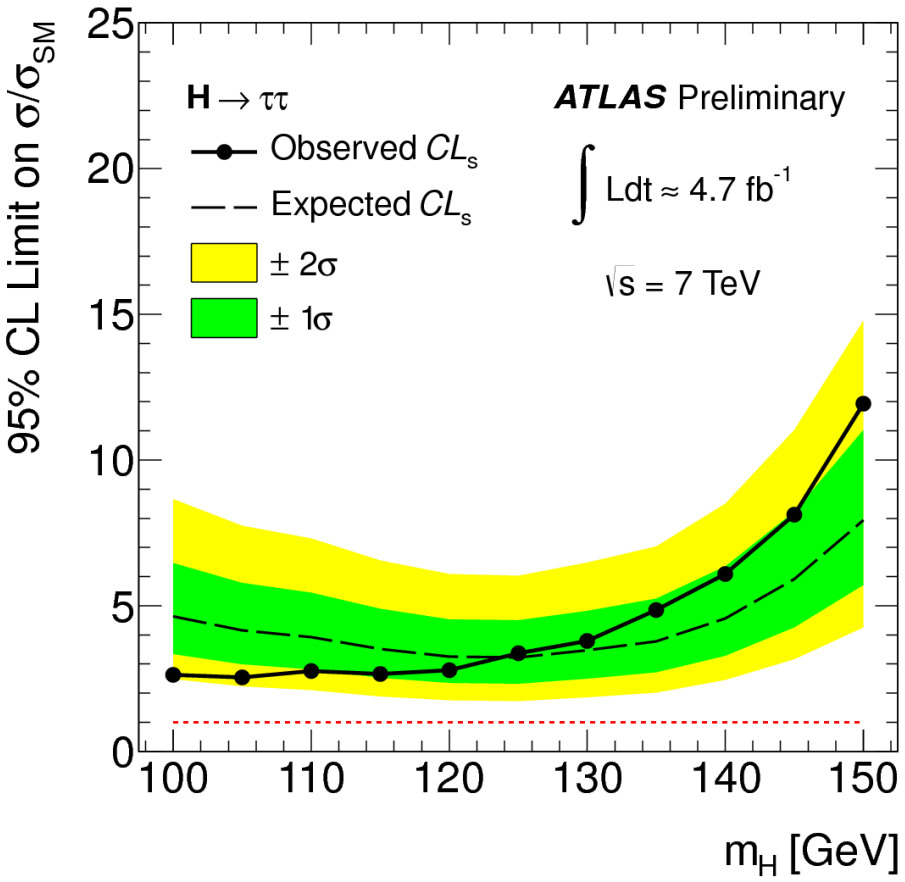
Z+jets

τ-embedded Z→μμ data normalized in fit before 1 jet selection

Multijet background

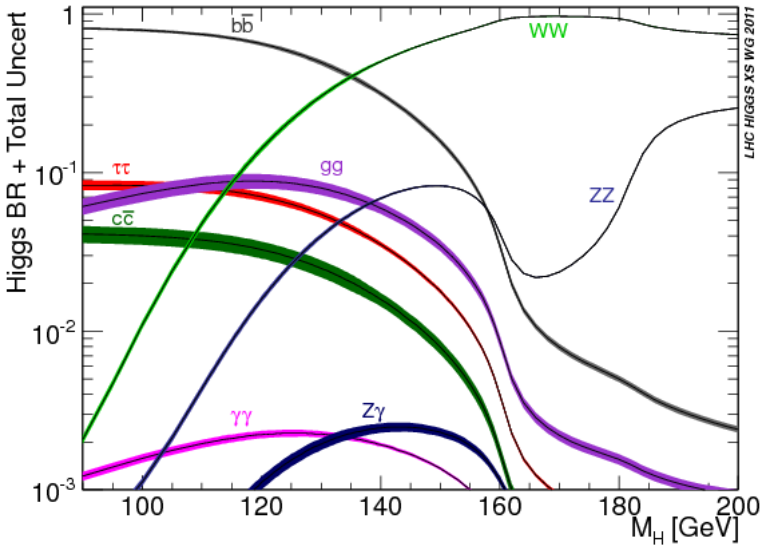
2D template fit of number of tracks for both τ candidates

H→ττ Exclusion Limit



- No significant excess
- 95% confidence level exclusion limit based on CL_s
- Observed (expected) exclusion between 2.5 (3.2) and 11.9 (7.9) x Standard Model cross section

Standard Model
VH, H → bb



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SM VH, H→bb: Analysis Channels

WH→lνbb	ZH→llbb	ZH→ννbb
Selection • $e/\mu, p_T > 25$ GeV • $E_{T,miss} > 25$ GeV • $m_T(e/\mu, E_{T,miss}) > 40$ GeV	**Selection** • $ee/\mu\mu, p_T > 20$ GeV • opposite charge • m_{ll} consistent with m_Z • $E_{T,miss} < 50$ GeV	**Selection** • $E_{T,miss} > 120$ GeV • $p_{T,miss} > 30$ GeV • $\Delta\varphi(E_{T,miss}, p_{T,miss}) < \pi/2$

2 b jets: $p_T > 45,25$ GeV

Limit derived based on m_{bb} distribution in bins of

$p_T^V < 50$ GeV
50 GeV $< p_T^V < 100$ GeV
100 GeV $< p_T^V < 200$ GeV
$p_T^V \geq 200$ GeV

120 GeV $< E_{T,miss} < 160$ GeV
160 GeV $< E_{T,miss} < 200$ GeV
$E_{T,miss} \geq 200$ GeV

SM VH, H→bb: Background Estimation

WH→lνbb

- Top/W shape from MC

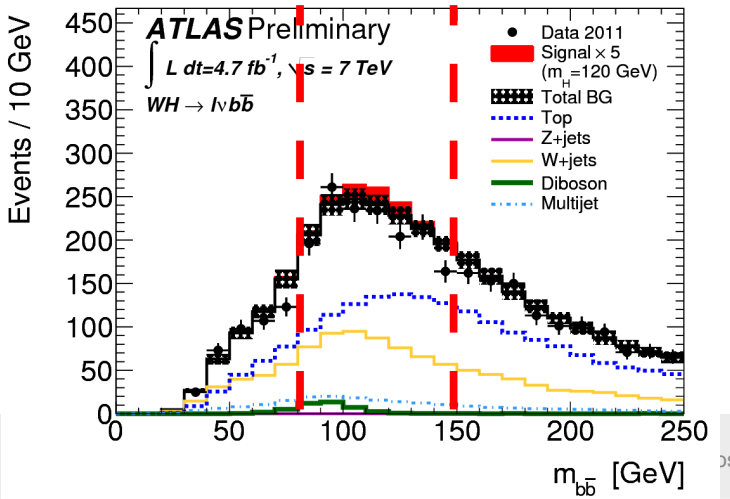
  Contribution of W+b,W+c,W+light reweighted by fit of b tag discrimination variable in W+2 jets sample

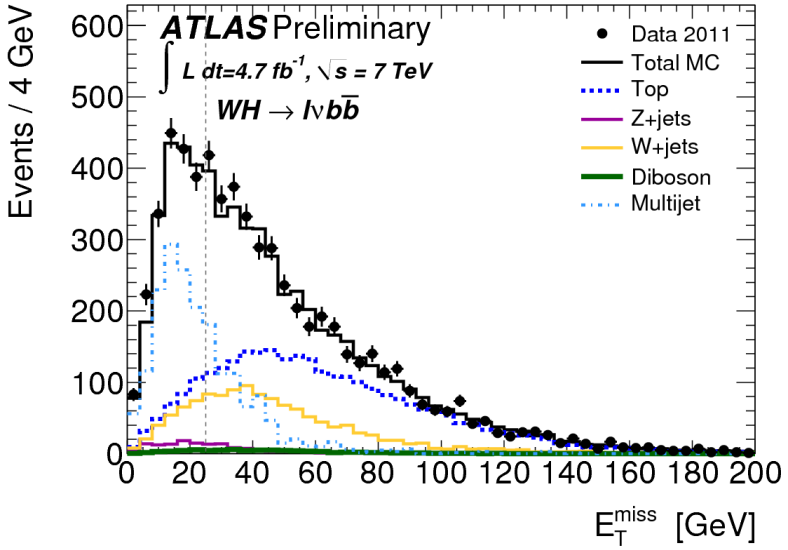
- Normalization from fit in control regions

  m_{bb} <80 GeV

  150 GeV < m_{bb} < 250 GeV

  3 jets (2 b jets) control region





- Multijet background estimation

  - Template from leptons which fail selection, but pass looser selection

  - Normalization by fit to $E_{T,miss}$ distribution

SM VH, H→bb: Background Estimation

ZH→llbb

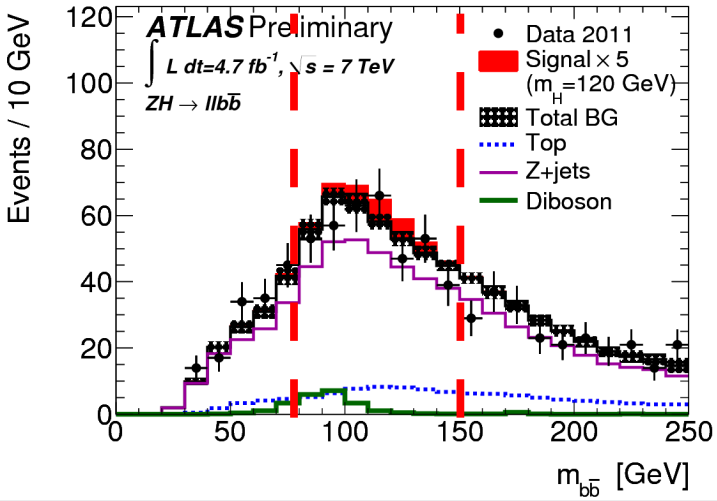
- Top/Z+jets shape from MC

  Contribution of Z+b,Z+c,Z+light reweighted by fit of b tag discrimination variable for Z+2 jets sample

- Normalization by fit in m_{bb} sidebands and

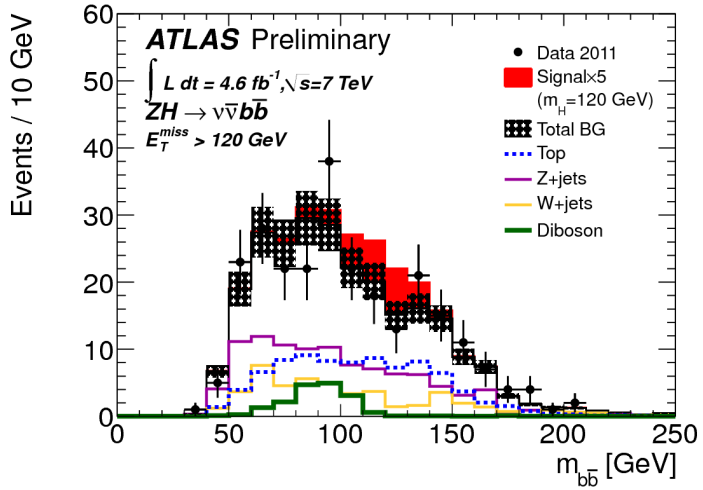
  60 GeV < m_{ll} <76 GeV

  106 GeV < m_{ll} < 150 GeV



ZH →ννbb

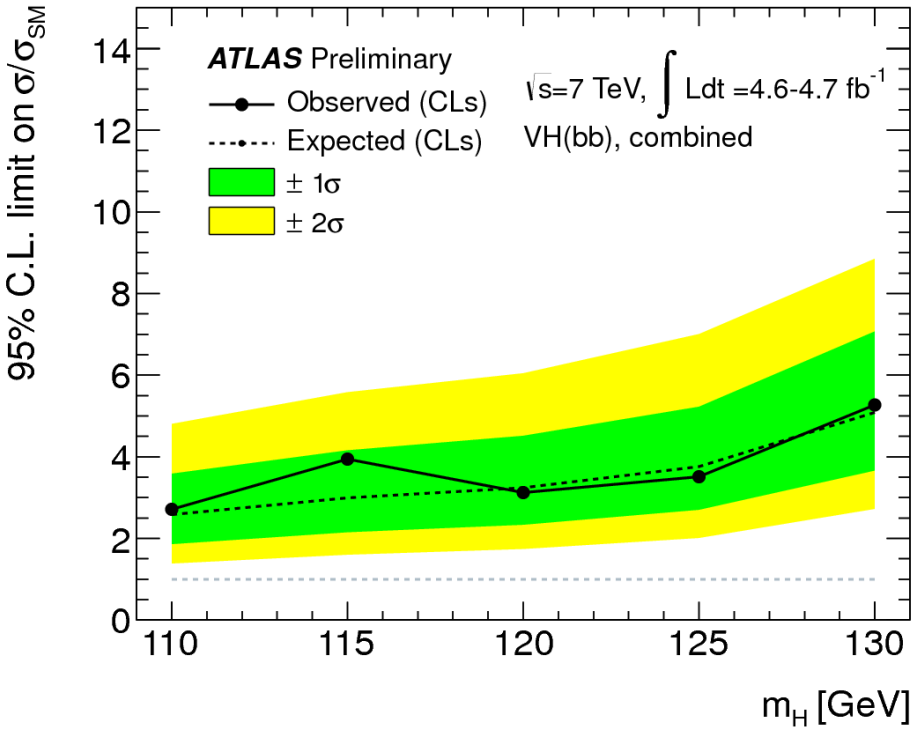
- Scale factors for top, Z, W backgrounds from other channels
- Multijet background estimation based $\Delta\varphi(E_{T,miss}, p_{T,miss})$ and $\min(\Delta\varphi(E_{T,miss}, \text{jets})$ consistent with 0



VH, H→bb: Systematic Uncertainties

Bin	$ZH \to \ell^+\ell^- b\bar{b}$ p_T^Z[GeV]				$WH \to \ell\nu b\bar{b}$ p_T^W[GeV]				$ZH \to \nu\bar{\nu}b\bar{b}$ E_T^{miss}[GeV]		
	0-50	50-100	100-200	>200	0-50	50-100	100-200	>200	120-160	160-200	>200
Components of the Background Systematic Uncertainties [%]											
B-tag Eff	3.1	2.8	2.2	7.7	1.4	1.7	2.5	11.3	4.1	9.2	15.6
Bkg Norm	5.2	5.0	5.2	5.6	4.0	2.8	2.7	5.5	3.1	3.9	4.2
Jets/E_T^{miss}	1.0	2.8	3.5	3.1	2.1	1.6	1.6	6.4	8.2	10.7	16.9
Leptons	0.4	0.5	1.1	3.6	1.0	0.4	0.7	6.1	-	-	-
Luminosity	0.2	0.1	0.2	0.4	0.1	0.1	0.1	0.2	0.2	0.5	0.8
Pile Up	0.7	1.8	1.5	6.9	0.6	0.7	1.1	2.5	0.7	2.6	1.9
Theory	7.3	1.7	7.2	23.4	3.1	1.0	1.1	11.9	3.7	6.3	11.1
Total Bkg	9.6	6.9	10.0	26.6	5.8	3.9	4.4	19.6	10.4	16.1	26.0
Components of the Signal Systematic Uncertainties [%]											
B-tag Eff	10	11	13	16	10	11	13	15	13	16	21
JES/MET	6.5	4.6	4.0	3.7	6.7	6.8	7.8	4.7	11.0	5.4	9.9
Leptons	1.1	1.5	1.5	3.6	3.2	4.2	5.0	5.5	-	-	-
Luminosity	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9
Pile Up	0.7	1.2	2.4	3.4	1.4	3.9	3.2	3.4	0.5	0.8	2.1
Theory	5	5	5	5	13	13	13	13	13	13	13
Total Signal	13.6	13.3	14.9	18.3	18.5	19.4	21.4	21.5	21.8	21.7	26.8

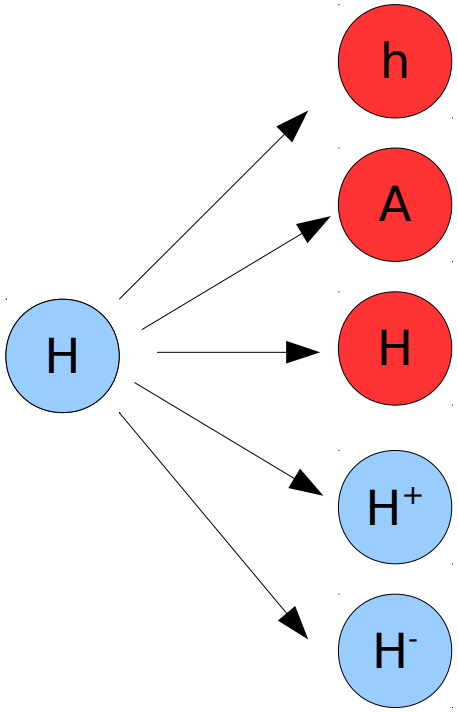
VH, H→bb: Exclusion Limit



- No excess of events over the expected background was found in data
- 95% confidence limit exclusion limit based on CL_s

MSSM

$h/A/H \rightarrow \tau\tau$



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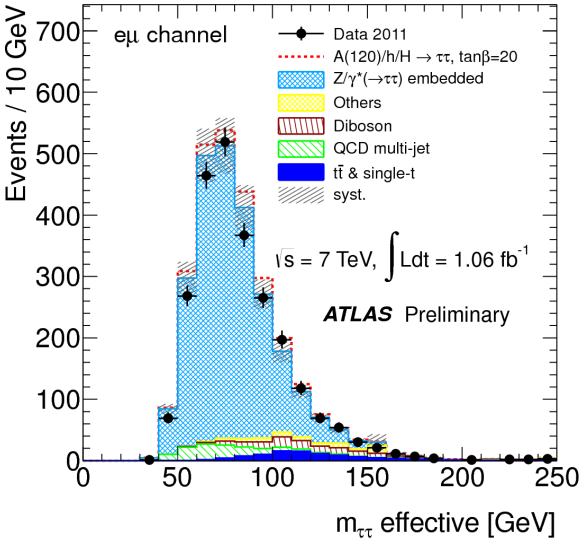
MSSM h/A/H → ττ

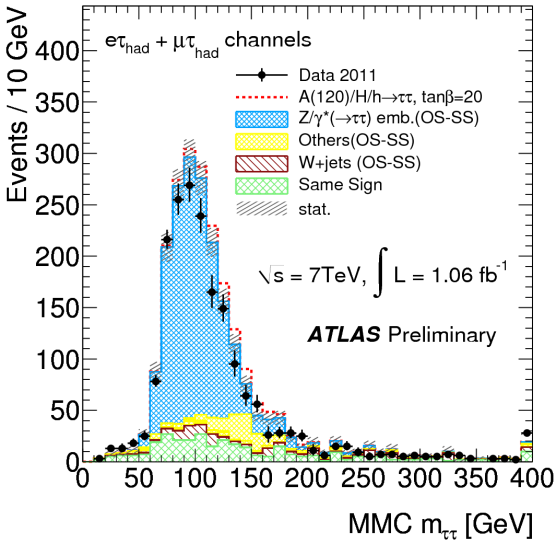
- For high tanβ decay into ττ enhanced
- Analysis selection and background estimation very similar to Standard Model analysis in the 0 jet channel

eμ channel



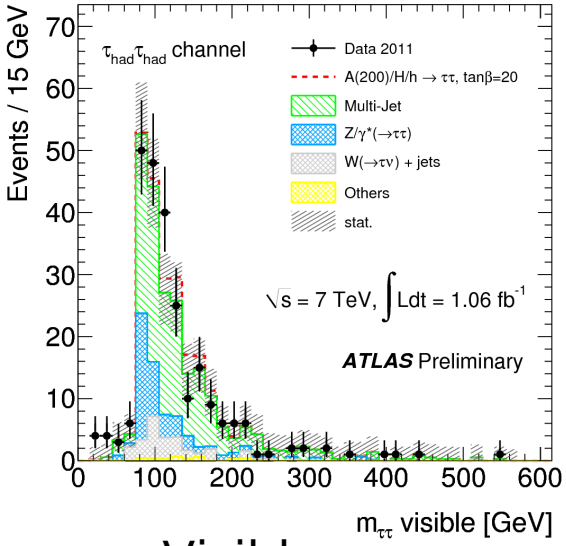
Effective mass

lh channel



MMC mass

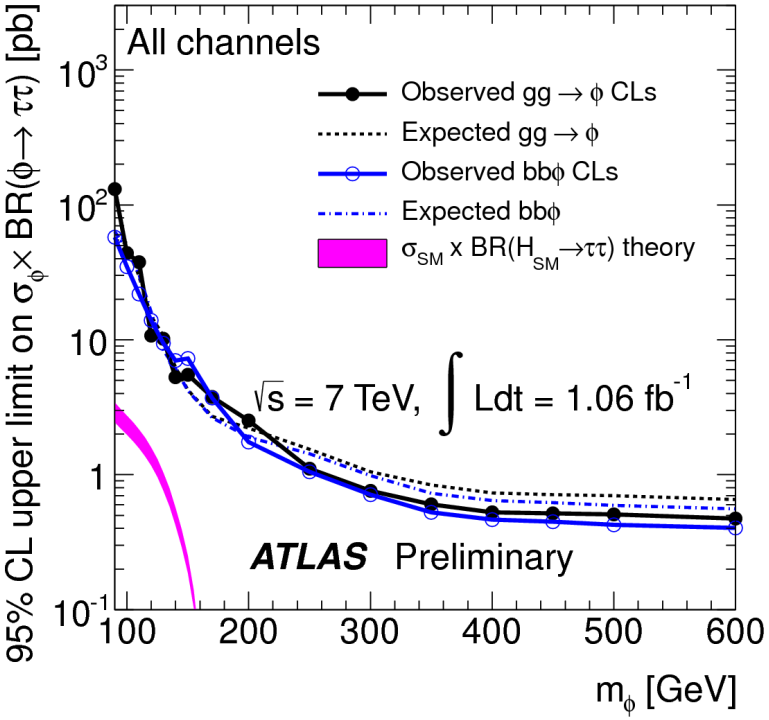
hh channel

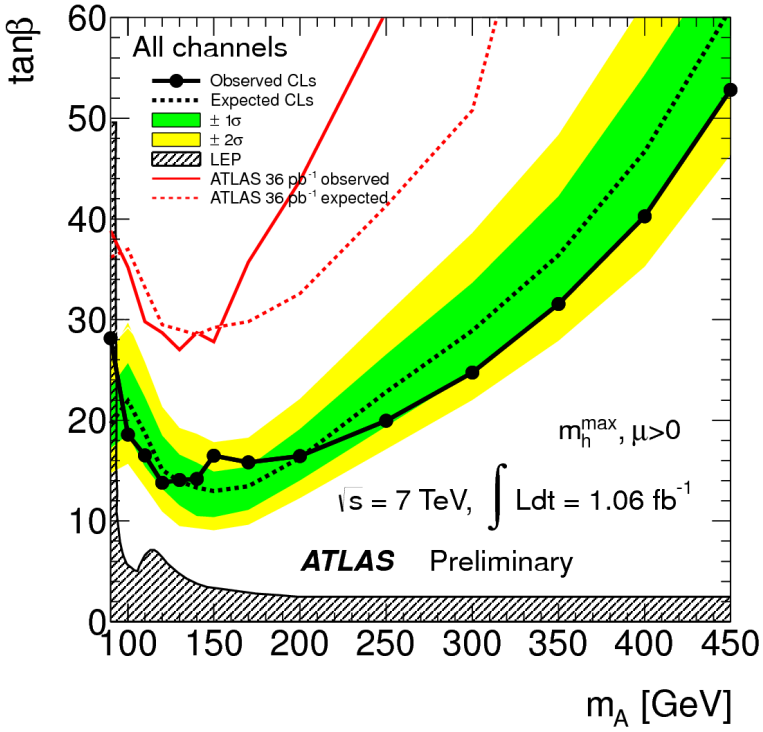


Visible mass

MSSM h/A/H → ττ

- For high tanβ decay into ττ enhanced
- Analysis selection and background estimation very similar to Standard Model analysis in the 0 jet channel





MSSM

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

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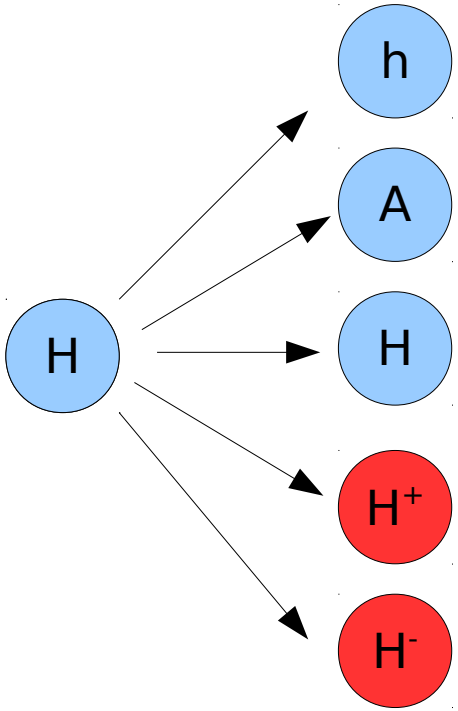

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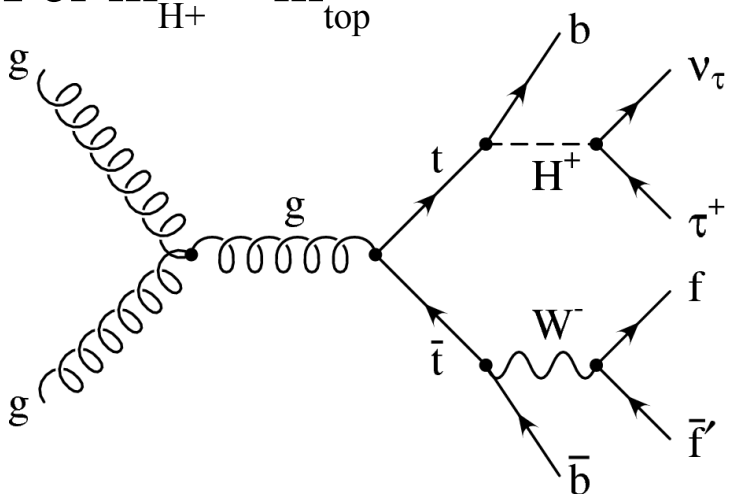
Charged Higgs

For $m_{H+} < m_{top}$



Analysis channels:

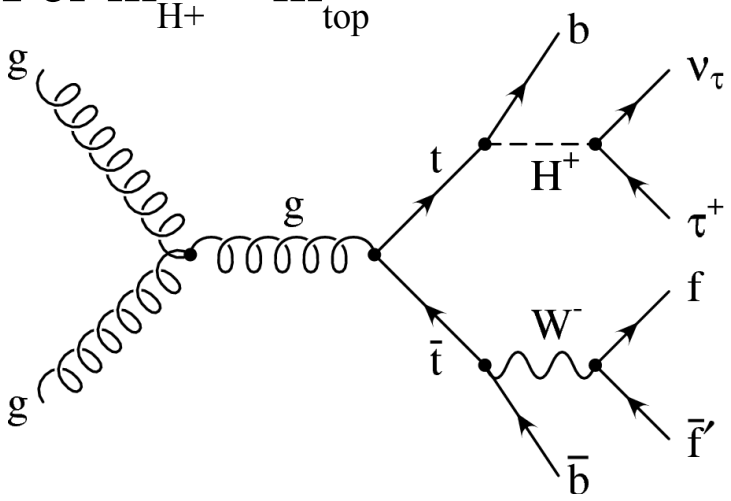
$$t\bar{t} \rightarrow b\bar{b}H^{\pm}W^{\mp} \rightarrow b\bar{b}(\tau_{lep}\nu)(q\bar{q}) : \underline{lepton + jets}$$

$$t\bar{t} \rightarrow b\bar{b}H^{\pm}W^{\mp} \rightarrow b\bar{b}(\tau_{had}\nu)(\ell\nu) : \underline{tau + lepton}$$

$$t\bar{t} \rightarrow b\bar{b}H^{\pm}W^{\mp} \rightarrow b\bar{b}(\tau_{had}\nu)(q\bar{q}) : \underline{tau + jets}$$

Charged Higgs

For $m_{H+} < m_{top}$



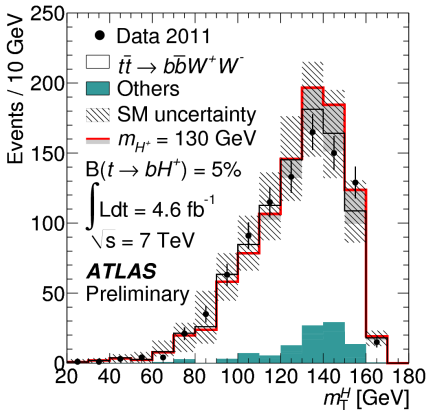
Analysis channels:

$$t\bar{t} \rightarrow b\bar{b}H^{\pm}W^{\mp} \rightarrow b\bar{b}(\tau_{lep}\nu)(q\bar{q}) : \underline{lepton + jets}$$

$$t\bar{t} \rightarrow b\bar{b}H^{\pm}W^{\mp} \rightarrow b\bar{b}(\tau_{had}\nu)(\ell\nu) : \underline{tau + lepton}$$

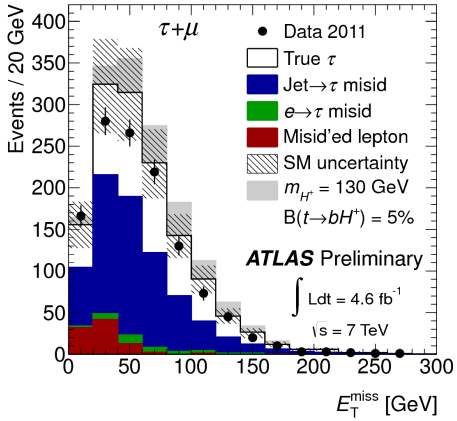
$$t\bar{t} \rightarrow b\bar{b}H^{\pm}W^{\mp} \rightarrow b\bar{b}(\tau_{had}\nu)(q\bar{q}) : \underline{tau + jets}$$

Lepton+jets:



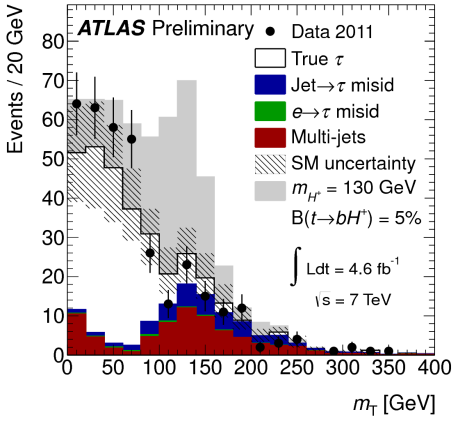
Upper bound on m_T ($W,H^{\pm}$)

τ_h + lepton:



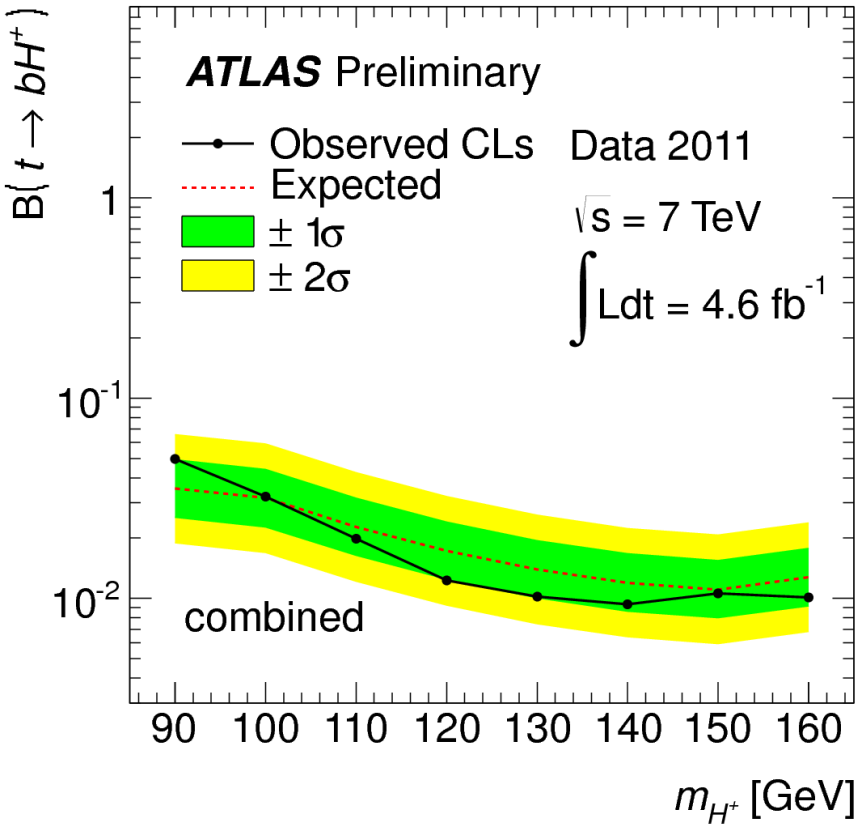
$E_{T,miss}$

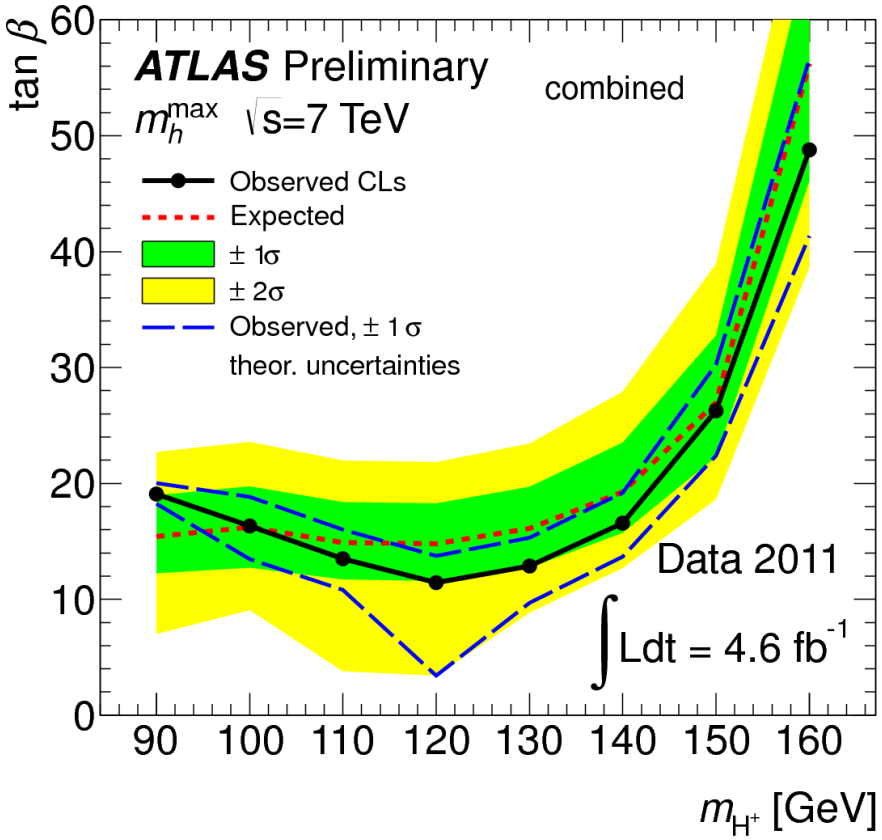
τ_h + jets:



$m_T(\tau,E_{T,miss})$

Charged Higgs: Exclusion Limit

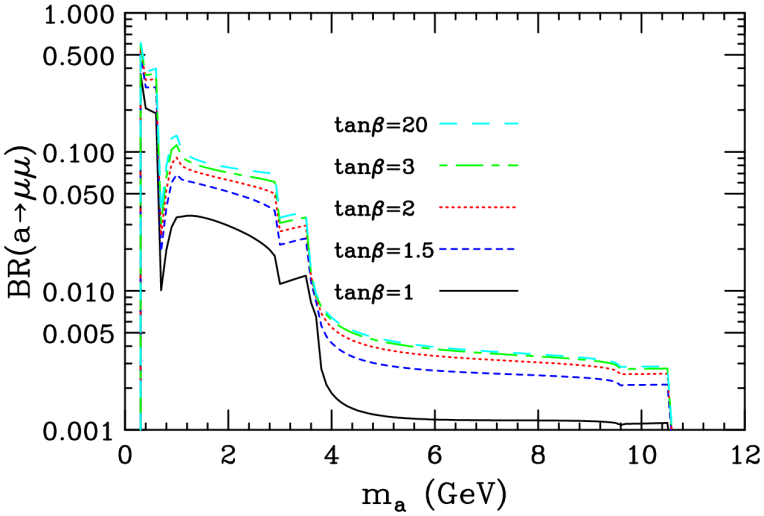




MSSM

NMSSM

$a_1 \rightarrow \mu\mu$



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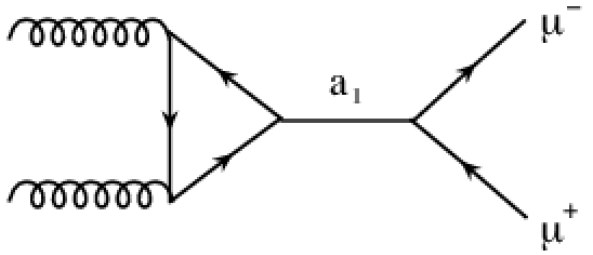
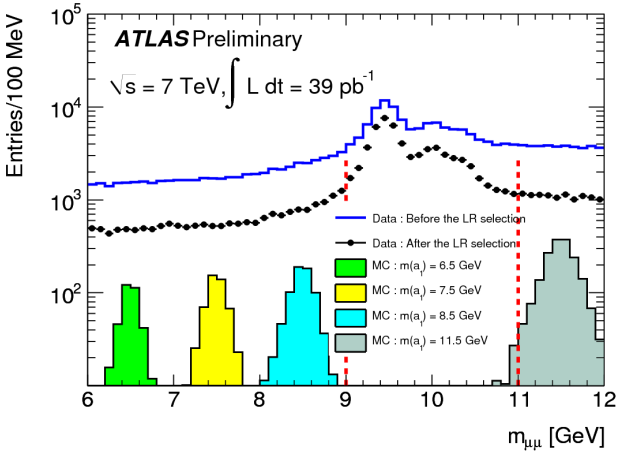
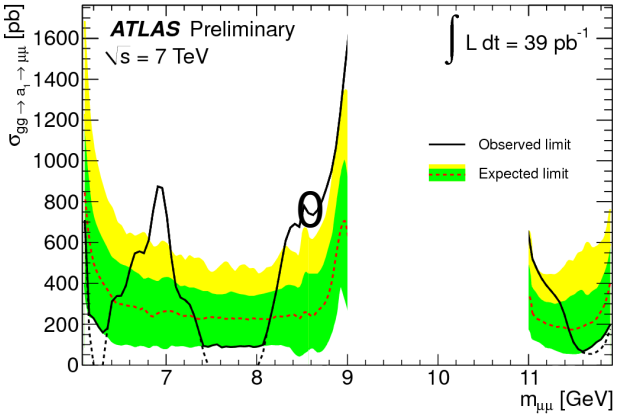
37/pb

NMSSM $a_1 \rightarrow \mu\mu$

- NMSSM: additional scalar singlet S
  - 2 CP odd Higgs fields: a_1,a_2
  - a_1 can be very light (10 GeV)
- Analysis selection:
  - 2 μ with p_T>4 GeV
  - 4.5 GeV < $m_{\mu\mu}$ < 14 GeV
  - Construct likelihood ratio from isolation and vertex fit quality
  - Background from $m_{\mu\mu}$ sidebands



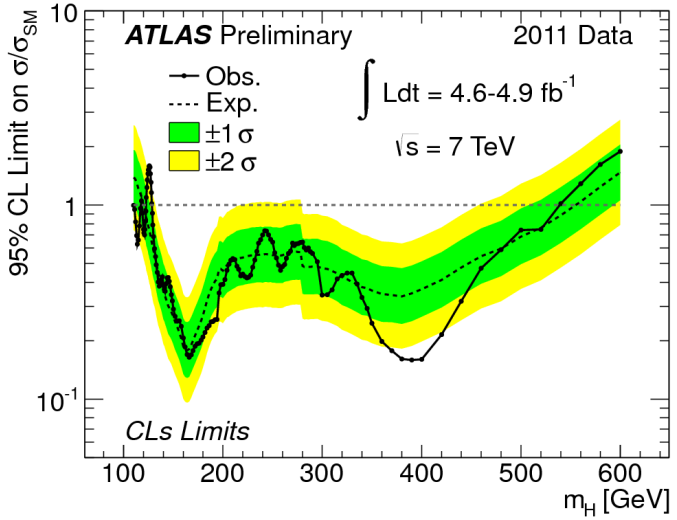




Summary

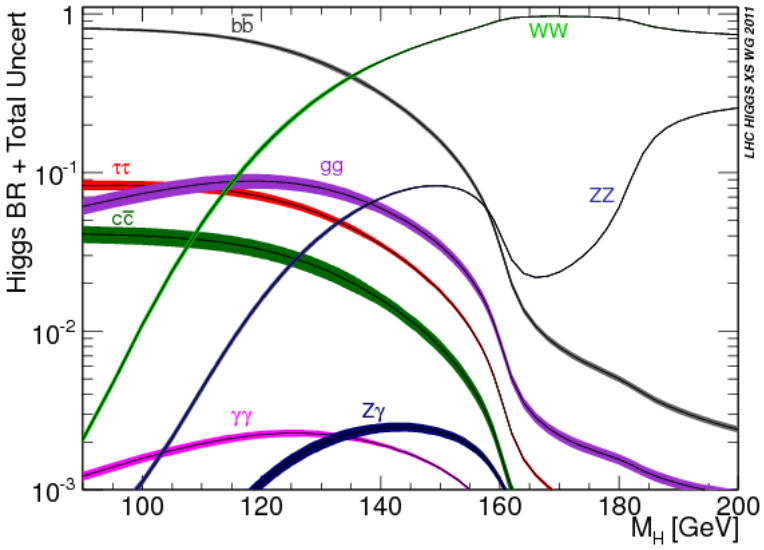
- The sensitivity in the H→fermions channels was increased significantly
- First LHC collisions with 8 TeV center of mass energy are currently being recorded
- The goal is to collect data corresponding to an integrated luminosity of 15/fb in 2012

→ There will certainly be interesting results from ATLAS in the search for the Higgs boson



Backup

Standard Model Combination



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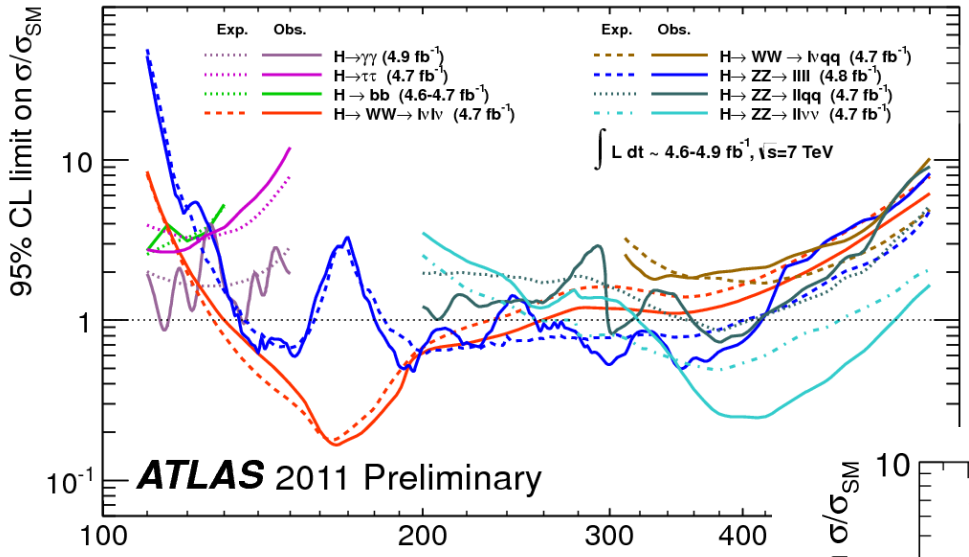
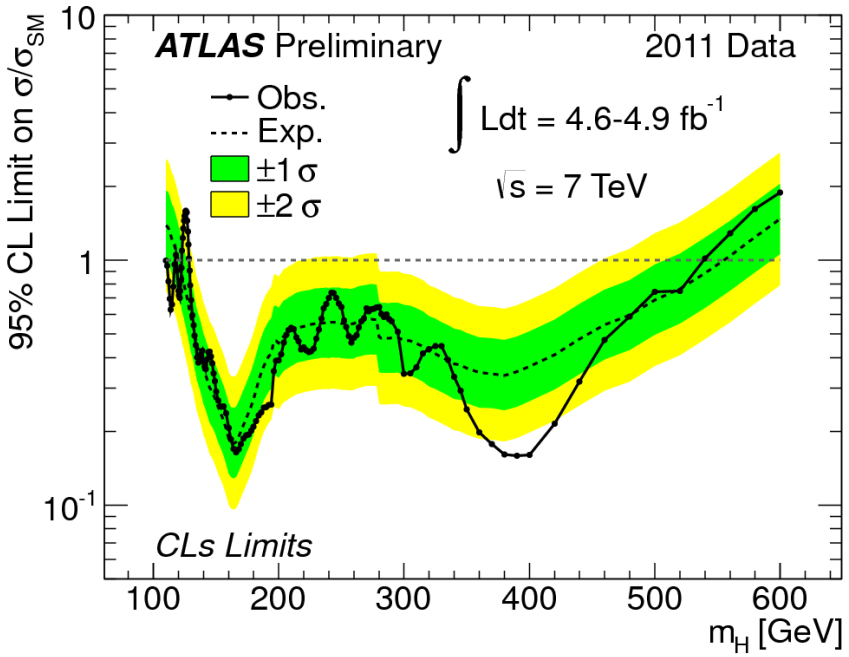
Standard Model: Limit Combination



Combination based on 68 signal and control regions

Exclusion at 95% CL of
- 110.0 GeV to 117.5 GeV,
- 118.5 GeV to 122.5 GeV,
- 129 GeV to 539 GeV

Excess with 2.5σ at 126 GeV



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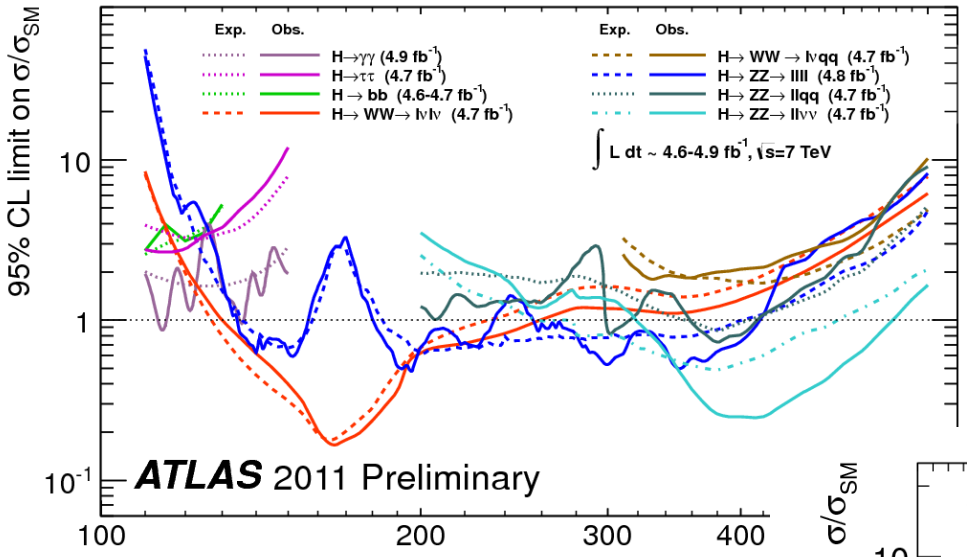

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