Searches for Beyond-Standard Model Higgs boson

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On Behalf of the ATLAS Collaboration

- Neutral Higgs Searches
  - ⇝ Fermiophobic Higgs
  - ⇝ MSSM $A/H/h \to \tau^+\tau^-$
  - ⇝ SM4 Interpretation
    will not be covered here.
    ATLAS-CONF-2011-135. $1.0 - 2.3\mathrm{fb}^{-1}$
  - ⇝ h→ long lived particles
    will not be covered here.
    arXiv:1203.1303 [hep-ex]. $1.94\mathrm{fb}^{-1}$
  - ⇝ nMSSM $a_1 \to \mu^+\mu^-$
    will not be covered here.
    ATLAS-CONF-2011-020. $39.3\mathrm{pb}^{-1}$
- Charged Higgs Searches
  - ⇝ $H^\pm \to \tau^\pm\nu$
  - ⇝ $H^\pm \to cs$
    will not be covered here.
    ATLAS-CONF-2011-094. $35\mathrm{pb}^{-1}$
- Doubly Charged Higgs Searches
  - ⇝ $H^{\pm\pm} \to \mu^\pm\mu^\pm$

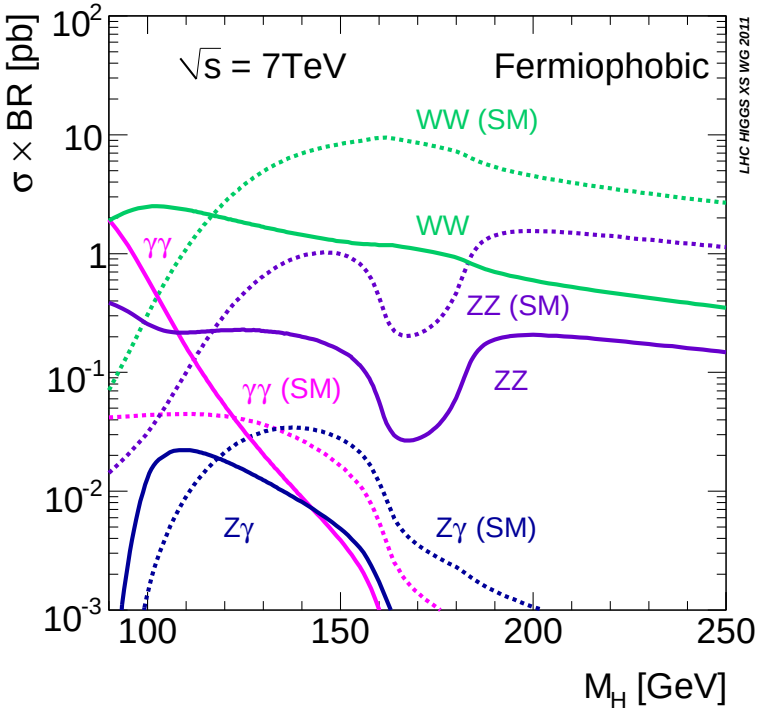
hep-ph/0608079v1

Fermiophobic Higgs

ATLAS-CONF-2012-013, arXiv:1205.0701v1 [hep-ex]. (4.9fb^{-1})

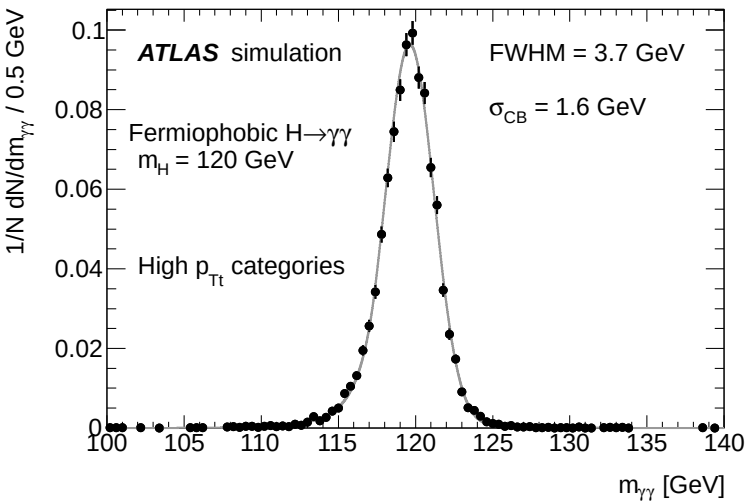
Fermiophobic Benchmark Scenario

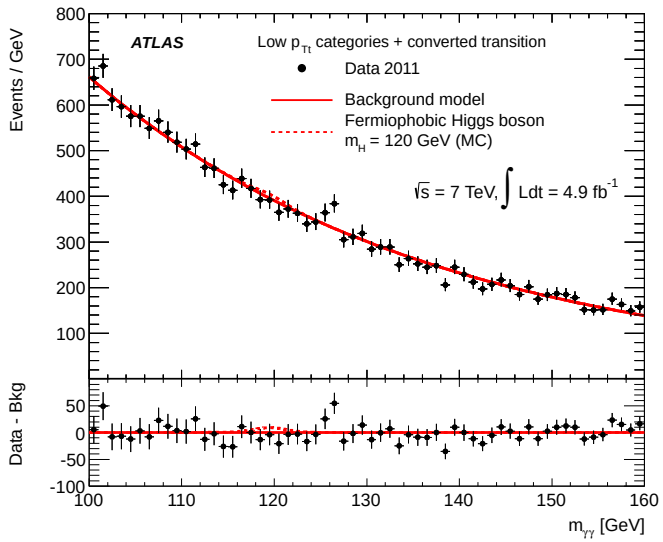
- Suppressed coupling of the Higgs to fermions (e.g. 2DHM, triplet models)
- Benchmark Scenario
  - ◯ Couplings to fermions are set to zero
  - √ Coupling to gauge bosons are set to SM values
- Channels
  - ⇝ Gluon fusion production is suppressed ⇒ boosted Higgs from VH and VBF
  - ⇝ $\sigma \times \text{BR}(H \to \gamma\gamma)$ is enhanced for $m_H < 120$ GeV

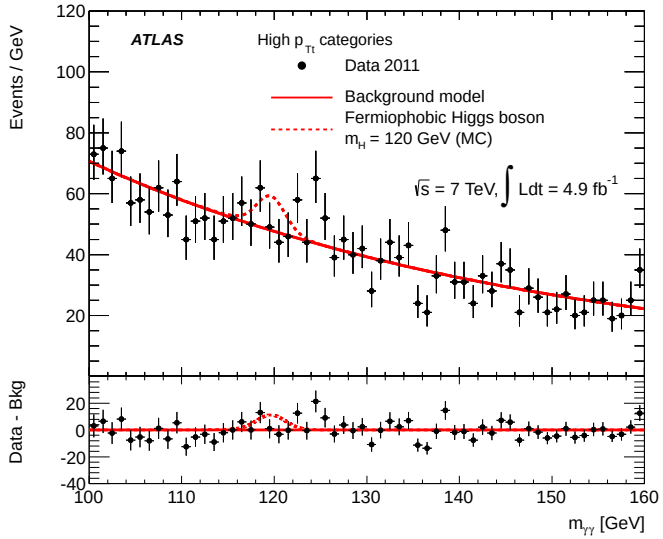


Fermiophobic Higgs

- Same selection as SM $H \to \gamma\gamma$
- 2 isolated photons
  $p_T > 40/20$ GeV
  $100 < m_{\gamma\gamma} < 160$ GeV
- 9 analysis categories based on:
  photon impact point in calorimeter
  photon conversion
  low/high p_{T_t} relative to 40 GeV
- Signal model: Crystal-Ball + Gaussian
  Background model: exponential



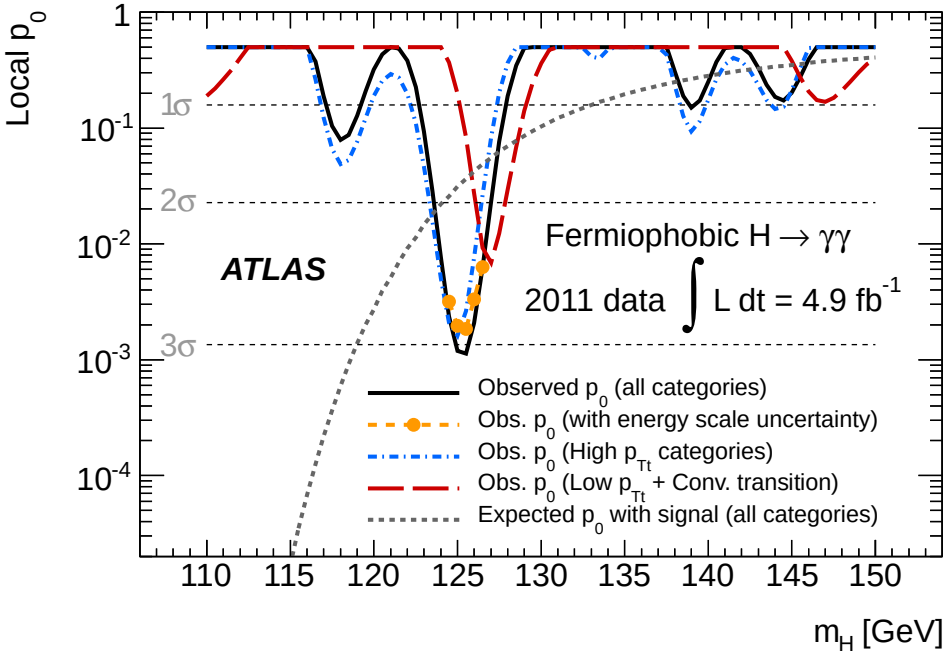


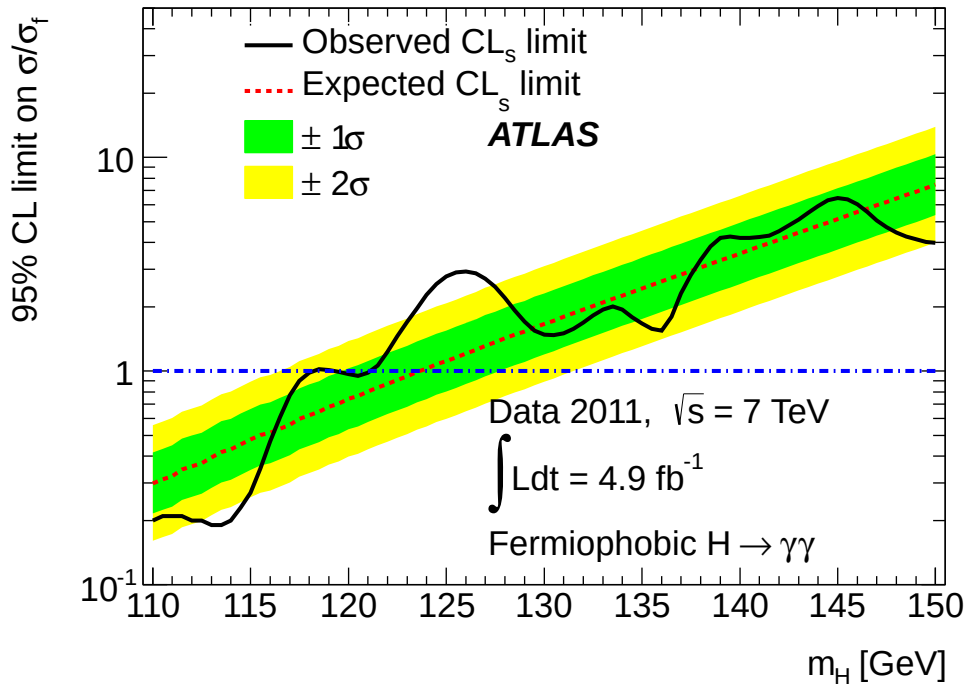


Fermiophobic Higgs: Limits

Observed exclusion (95% CL):
110.0 – 118.0 GeV
119.5 – 121.0 GeV

Expected exclusion (95% CL):
110.0 – 123.5 GeV





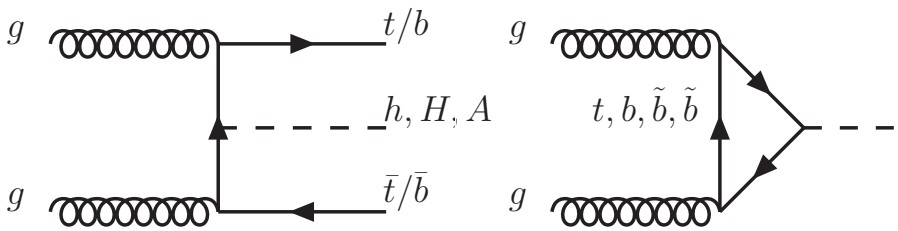
Observed largest excess at $m_H = 125.5$ GeV
local: 2.9σ
global: 1.6σ

MSSM $A/H/h \to \tau^+\tau^-$

ATLAS-CONF-2011-132. ($1.06\,\mathrm{fb}^{-1}$)

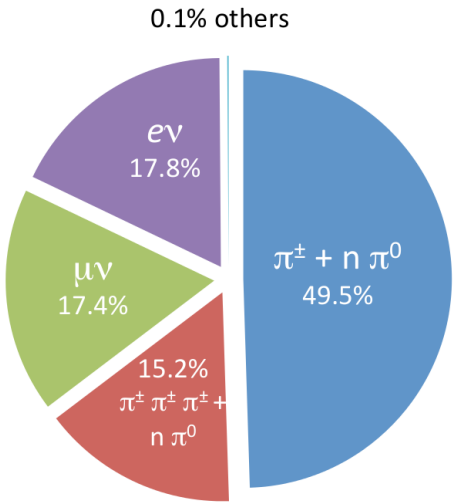
MSSM Higgs sector

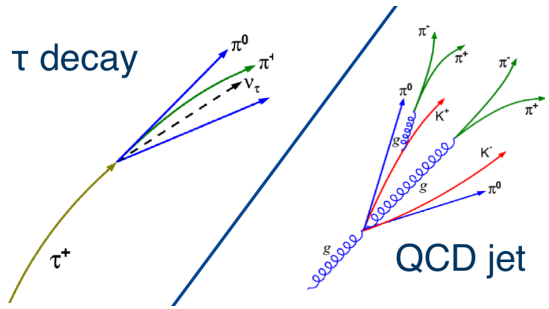
- 2 Higgs doublets
  light and heavy scalars: h, H
  pseudo-scalar: A
  charged: $H^{\pm}$
- m_h^{max} benchmark scenario
  free parameters m_A, $\tan\beta$
- for high $\tan\beta$
  coupling to down-type fermions enhanced
  coupling to gauge bosons suppressed
  $\mathrm{BR}(\Phi \to \tau\tau) \approx 10\%$
- Search for the collective signature of h, H and A



τ decays

- Tag unique signature of hadronic taus:
  narrow, collimated jet
  isolated energy deposit and tracks
  large EM component
  track multiplicity 1 or 3 high leading track momentum fraction
- efficiency: $\sim 60\%$
  misidentification rate: $\sim 5\%$





MSSM $A/H/h \to \tau^+\tau^-$: Event selection

electron-muon

- Opposite sign, isolated, high p_T $e\mu$ pair
- $p_T^e + p_T^\mu + \not{E}_T < 120\text{GeV}$
- $\Delta\phi_{e\mu} > 2$

$$m_{\tau\tau}^{eff} = \sqrt{\left(p_e + p_\mu + p_{\not{E}_T}\right)^2}$$

lepton-hadron

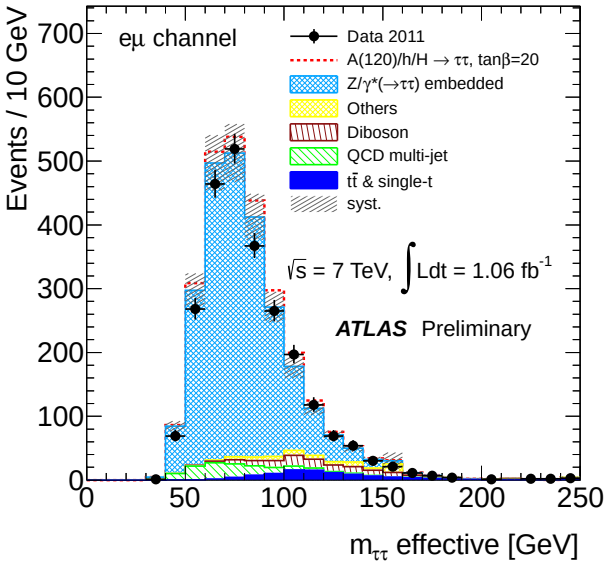
- Opposite sign, isolated, high p_T $\ell\tau_{had}$ pair
- dilepton veto
- $\not{E}_T > 20$ GeV
- $m_T^W < 30$ GeV

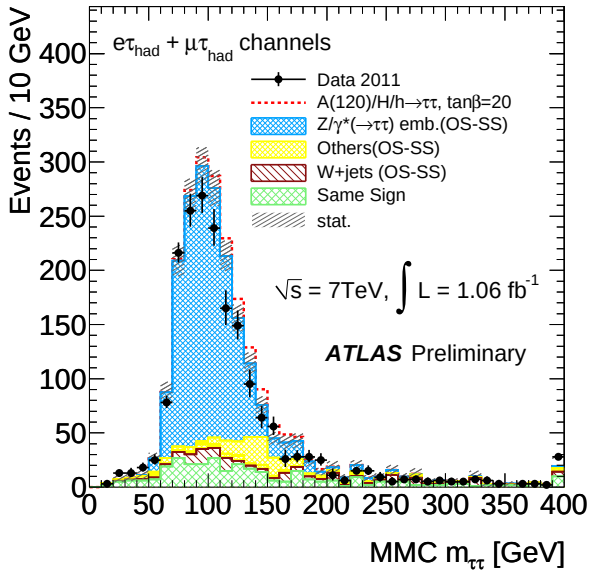
max. prob. $m_{\tau\tau}$ (MMC)

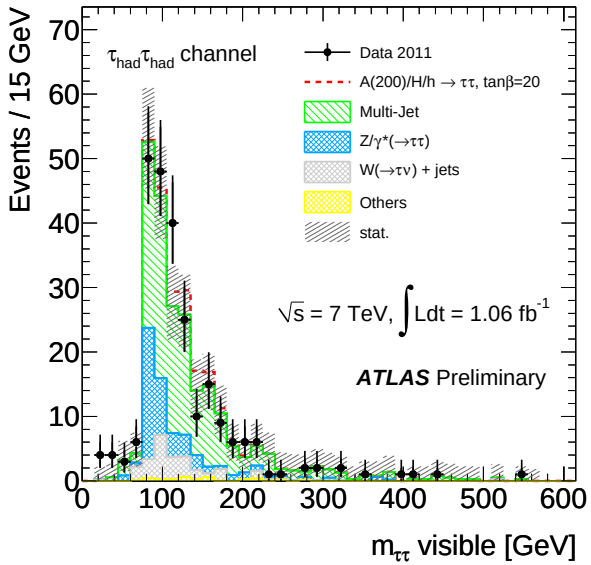
hadron-hadron

- di-τ_{had} trigger
- Opposite sign di-τ_{had} $p_T > 45/30$ GeV
- lepton veto
- $\not{E}_T > 25$ GeV

$$m_{vis} = \sqrt{\left(p_{\tau_{had1}} + p_{\tau_{had2}}\right)^2}$$







MSSM $A/H/h \to \tau^+\tau^-$: Embedding

model $Z/\gamma^* \to \tau\tau$

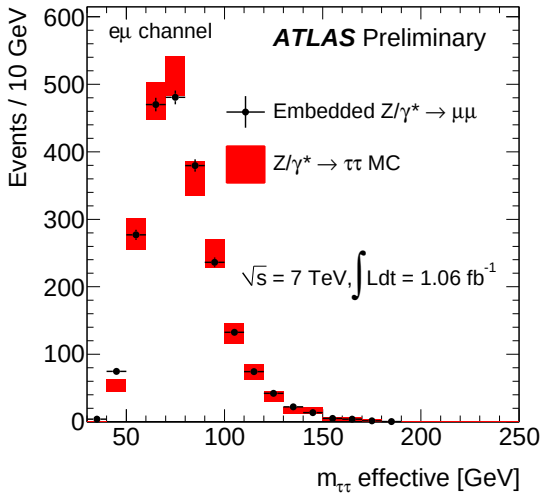
- $e\mu \sim 90\%$
  $\ell\tau_{had} \sim 70\%$
  $\tau_{had}\tau_{had} \sim 20\%$

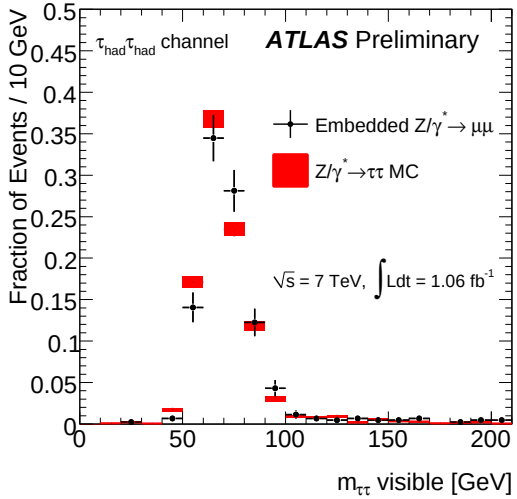
1. Measure high p_T di-μ, $m_{\mu\mu} > 40$ GeV
2. Remove muon hits
3. Simulate Tau decay
4. Normalize to MC

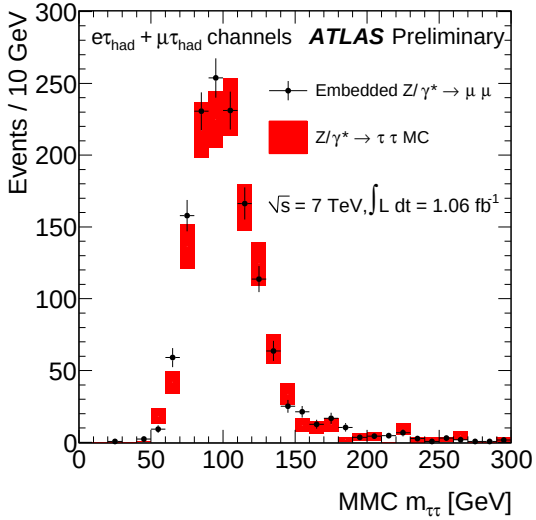
model $W \to \tau\nu$

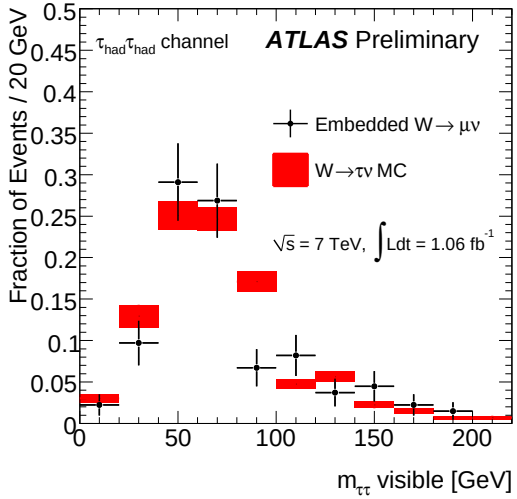
- $\tau_{had}\tau_{had} \sim 10\%$

1. Measure high p_T muons, $m_T^W > 40$ GeV
2. Remove muon hits
3. Simulate Tau decay
4. Normalize to MC





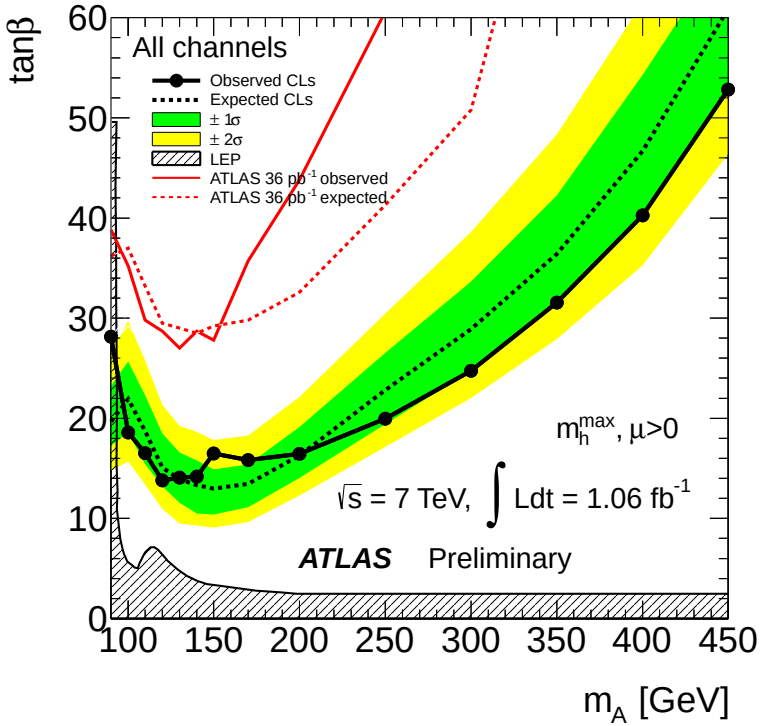


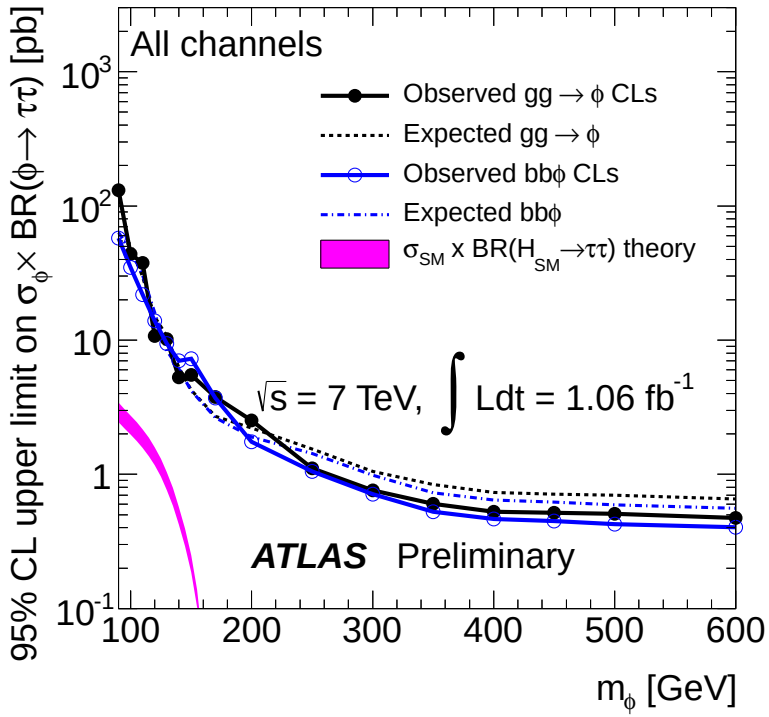


Note - Embedding procedure in the $\tau_{had}\tau_{had}$ is a cross check for MC

MSSM $A/H/h \to \tau^+\tau^-$: Exclusion plots

Exclusion @ 95% CL





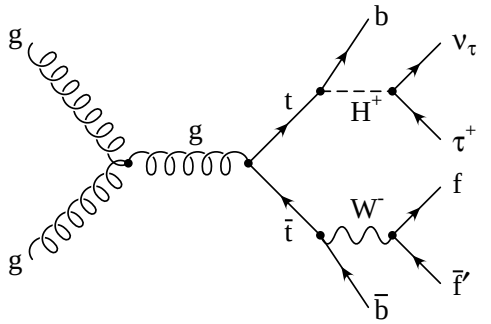
$H^{\pm} \to \tau^{\pm}\nu$

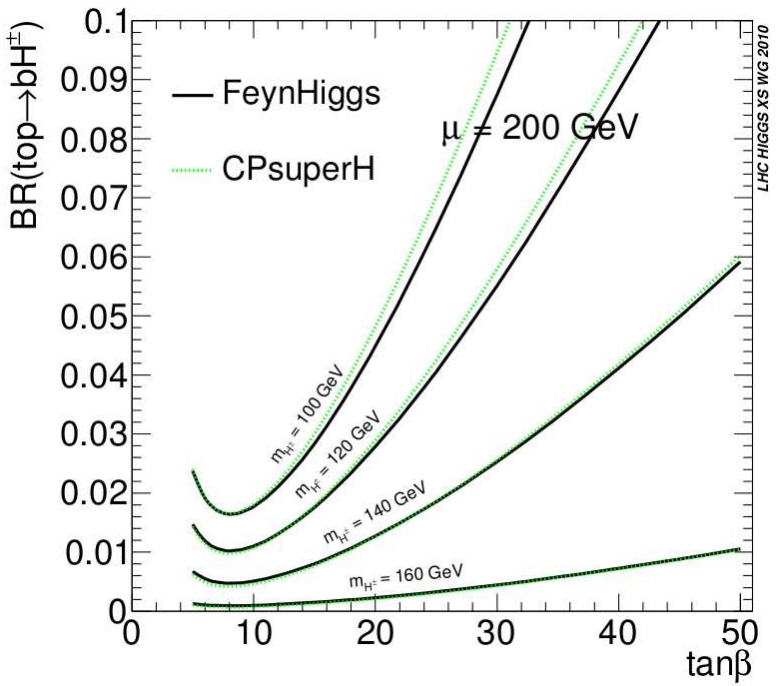
ATLAS-CONF-2012-011, arXiv:1204.2760v1 [hep-ex] (4.6fb^{-1})

- Exist in non-minimal Higgs scenarios (e.g. 2DHM, Higgs triplet models)
- production and decay:
  $m_{H^{\pm}} < m_t \Rightarrow t \to bH^+$
  $\tan\beta > 2 \Rightarrow H^+ \to \tau\nu$ dominant
- heavy $H^{\pm}$:
  $m_{H^{\pm}} < m_t \Rightarrow gb \to tH^+$
  more data is needed

Search channels

$t\bar{t} \to b\bar{b}H^{\pm}W^{\mp} \to b\bar{b}\,(\tau_{\ell}\nu)\,(q\bar{q})$
$t\bar{t} \to b\bar{b}H^{\pm}W^{\mp} \to b\bar{b}\,(\tau_{had}\nu)\,(\ell\nu)$
$t\bar{t} \to b\bar{b}H^{\pm}W^{\mp} \to b\bar{b}\,(\tau_{had}\nu)\,(q\bar{q})$



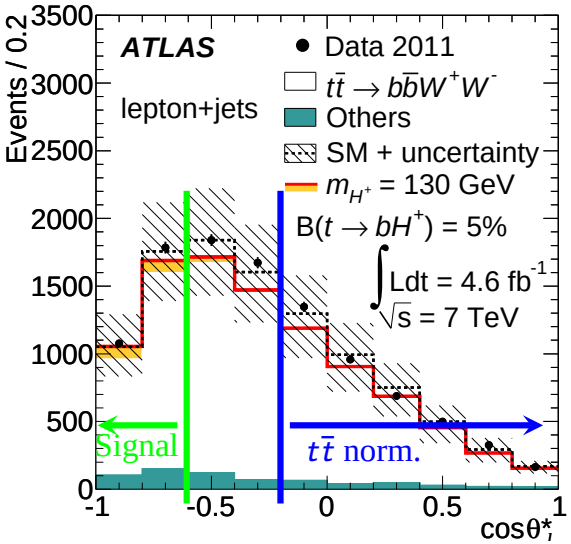


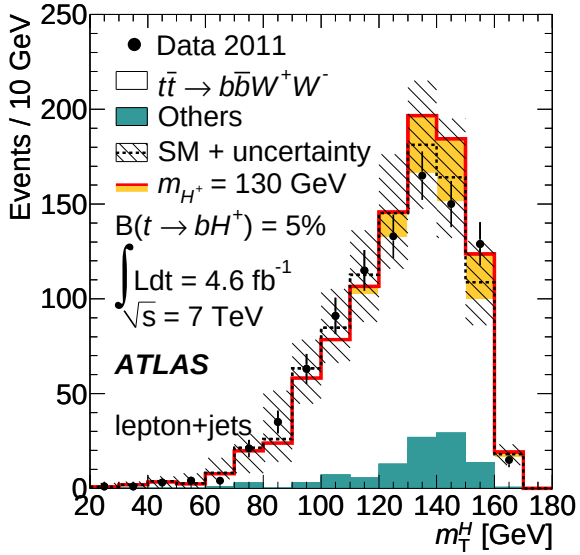
$H^{\pm} \to \tau_{\ell}\nu$: Event selection

Selection in $H^{\pm} \to \tau_{\ell}\nu$

- 1 isolated high p_T lepton
- 4 or more high p_T jets
- 2 b-tag
- $\left|\phi_{\ell,\mathrm{miss}}\right| \geq \pi/6 \Rightarrow \not{E}_T > 40\ \mathrm{GeV}$
  $\left|\phi_{\ell,\mathrm{miss}}\right| < \pi/6 \Rightarrow \not{E}_T \left|\sin\left(\phi_{\ell,\mathrm{miss}}\right)\right| > 20\ \mathrm{GeV}$
- event kinematics consistent with signal topology
- $\cos\theta^*_{\ell} < -0.6$ (normalize $t\bar{t}$ at $\cos\theta^*_{\ell} > -0.2$)
- $m_T^W < 60\ \mathrm{GeV}$

- $\cos\theta^*_{\ell} = \frac{2m^2_{b\ell}}{m_t^2 - m_W^2} - 1 \approx \frac{4p^b \cdot p^{\ell}}{m_t^2 - m_W^2} - 1$
- $(m_T^H)^2 = \left(\sqrt{m_t^2 + \left(\vec{p_T}^{\,\ell} + \vec{p_T}^{\,b} + \vec{\not{p}}_T\right)^2 - p_T^b}\right)^2 - \left(\vec{p_T}^{\,\ell} + \vec{\not{p}}_T\right)^2$





$H^{\pm} \to \tau_{had}\nu$: Event selection

Selection in lepton + $H^{\pm} \to \tau_{had}\nu$

- isolated, opposite sign, high p_T $\ell\tau_{had}$ pair
- ≥ 2 high p_T jets
- at least 1 b-tag
- large p_T carried by tracks from primary vertex

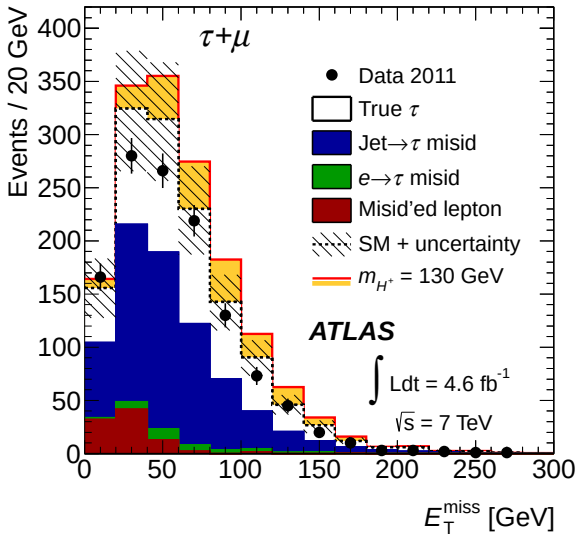
$\not{E}_T$ as discriminating variable

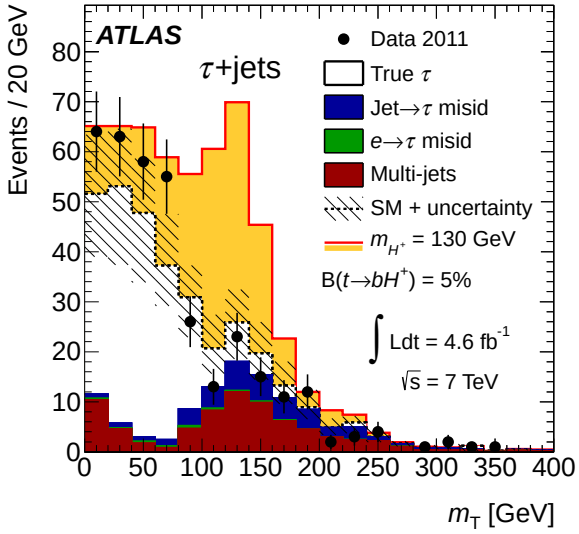
Selection in jets + $H^{\pm} \to \tau_{had}\nu$

- high p_T τ_{had} and $\not{E}_T$
- ≥ 4 high p_T jets (non tau)
- at least 1 b-tag
- lepton veto
- large $\not{E}_T$ significance
- jet kinematics consistent with signal topology

transverse mass as discriminating variable

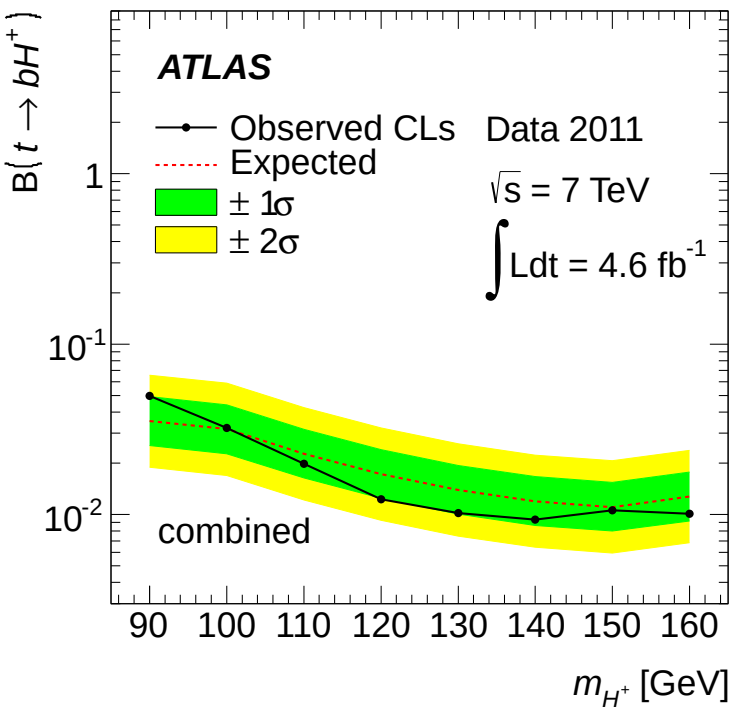
$$m_T = \sqrt{2p_T^{\tau}\not{E}_T\left(1-\cos\phi_{\tau,\mathrm{miss}}\right)}$$

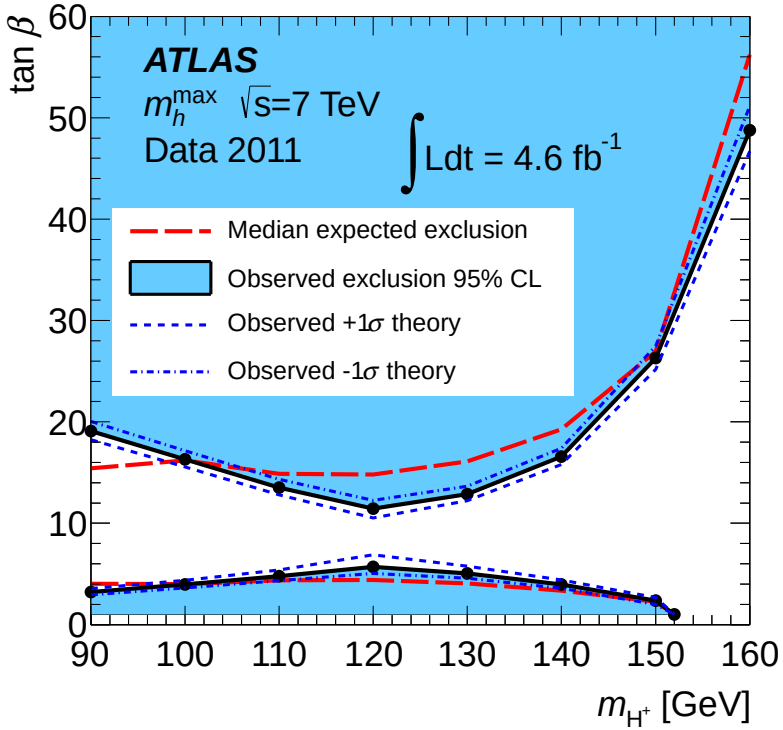




$H^{\pm} \to \tau\nu$: Limits

Exclusion @ 95% CL

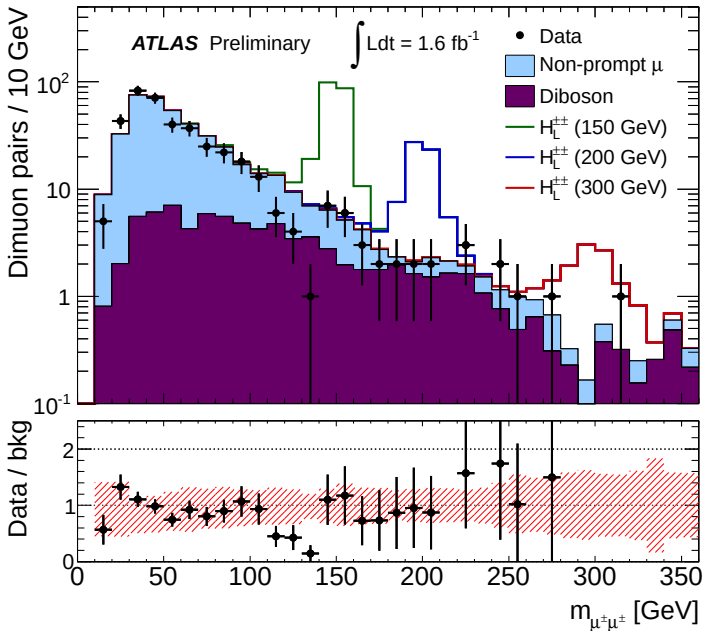




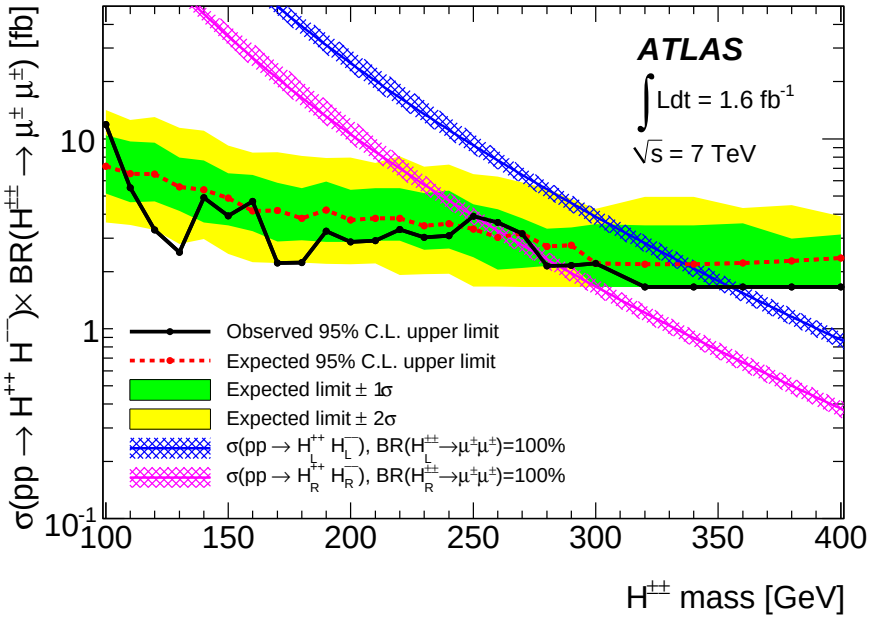
$H^{\pm\pm} \to \mu^{\pm}\mu^{\pm}$

Phys.Rev.D 85 (2012) 032004 (1.6fb^{-1})

- Exist in left-right symmetric models, Higgs triplet and little higgs models
- dominant production $pp \to H^{++}H^{--}$
- Inclusive search for same-sign muons
- background
  prompt muons (di-boson - MC)
  non-prompt muons (control region)



- No excess was observed
- Set limit assume production mechanism $pp \to Z/\gamma^* \to H^{++}H^{--}$



$\text{BR}\left(H^{\pm\pm} \to \mu^{\pm}\mu^{\pm}\right)$	$= 100\%$	$= 33\%$
$H_R(\text{GeV})$	< 251	< 209
$H_L(\text{GeV})$	< 355	< 244

Conclusion

- Many BSM higgs models were considered
- (Still) no deviation from SM was observed
- Strict upper limits were placed
- New data is coming, stay tuned