Search for Charged Higgs Bosons in ATLAS

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Motivation

In several theories beyond the Standard Model (SM), including the Minimal Supersymmetric Model (MSSM), two doublets of scalar fields, and thereby five physical states, are predicted in the Higgs sector. Two of these are charged (H^+ and H^-) and, among the three neutral Higgs bosons, two are CP-even states, h^0 and H^0, and one is CP-odd, A^0. In the MSSM, a light H^+ decays primarily to $c\bar{s}$, $b\bar{b}W^+$ and $\tau^+\nu$, depending on $\tan\beta$ and m_{H^+}. For $\tan\beta > 3$, $\mathcal{B}(H^+ \to \tau\nu)$ exceeds 90%.
The aim of the analyses presented here is to search for the charged Higgs boson in $t\bar{t}$ decays with a hadronically or leptonically decaying τ lepton in the final state. 1.03 fb^{-1} of ATLAS data have been analysed.

Single- and Di-Lepton Final States

Single-Lepton

Event selection:
- 1 trigger-matched lepton
- at least 4 jets
- 2 b jets
- E_T^{miss}

The assignment of the b jets is done by minimising:

$$\chi^2 = \frac{(M_{jjb} - M_{top})^2}{\sigma_{top}^2} + \frac{(M_{jj} - M_W)^2}{\sigma_W^2}$$

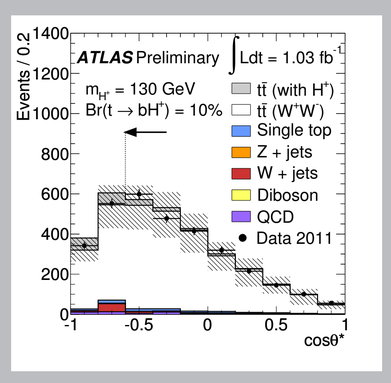

Figure 1: Single lepton $\cos\theta_l^*$ distribution.

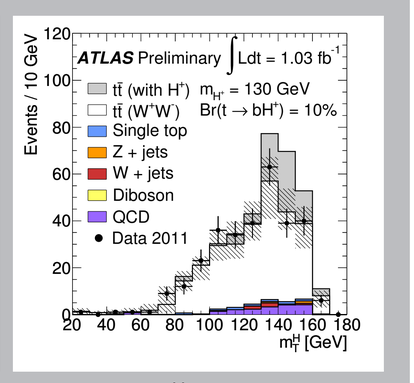

Figure 2: m_T^H distribution for events with $\cos\theta_l^* < -0.6$ and $m_T^W < 60$ GeV.

- $\cos\theta_l^* = \frac{2m_{bl}^2}{m_{top}^2 - m_W^2} - 1 \simeq \frac{4\,p^b \cdot p^l}{m_{top}^2 - m_W^2} - 1$

  with p^b and p^l being the 4-momenta of the b quark and charged lepton l (electron or muon) and m_{bl} being their invariant mass.
- Novel transverse mass: $(m_T^H)^2 = \left(\sqrt{m_{top}^2 + (\vec{p}_T^{\,l} + \vec{p}_T^{\,b} + \vec{p}_T^{\,miss})^2} - p_T^b\right)^2 - \left(\vec{p}_T^{\,l} + \vec{p}_T^{\,miss}\right)^2$

$t\bar{t}$ ($bbWW$)	Single top-quark	W+jets	Z+jets	Diboson	QCD	$\sum$ SM	Data	130 GeV H^+ $\mathcal{B}(t \to bH^+) = 10\%$
3081	88	85	5.2	2.0	56	3317	3421	190

Table 1: Expected and observed number of events with $\int \mathcal{L}dt = 1.03$ fb^{-1}, a fitted value of 165.1 pb is used for σ_{bbWW}.

Di-Lepton

Event selection:
- 2 oppositely charged leptons with at least one trigger-match
- at least 2 jets
- 2 b jets
- E_T^{miss} cut

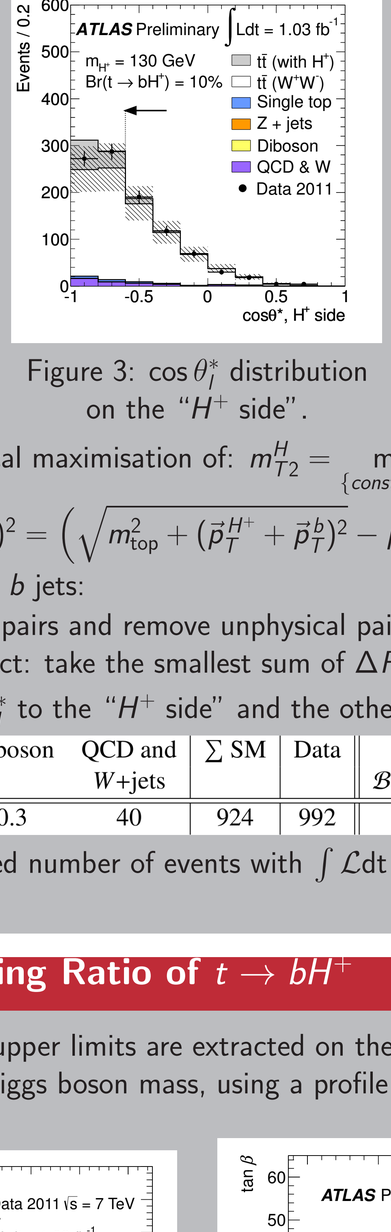

Figure 3: $\cos\theta_l^*$ distribution on the "H^+ side".

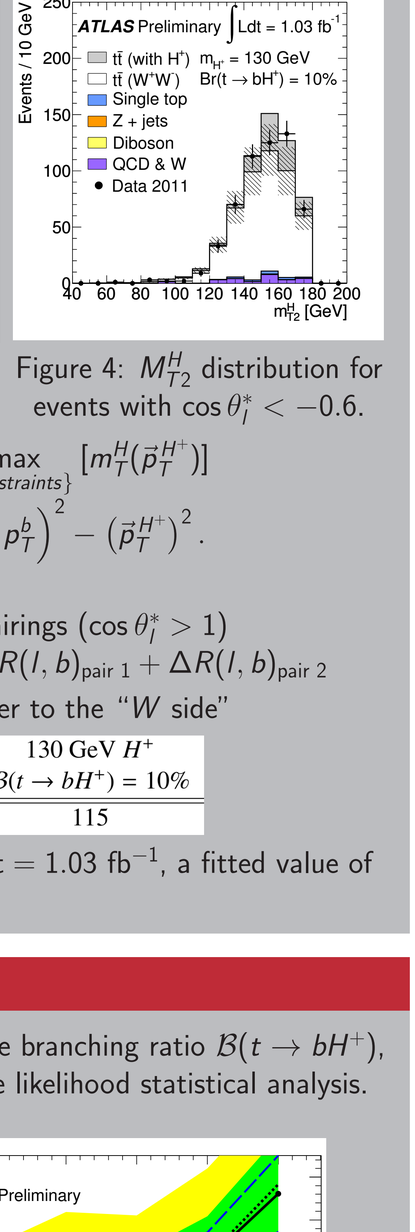

Figure 4: M_{T2}^H distribution for events with $\cos\theta_l^* < -0.6$.

m_{T2}^H is computed by a numerical maximisation of: $m_{T2}^H = \max_{\{constraints\}}[m_T^H(\vec{p}_T^{\,H^+})]$

with the definition: $(m_T^H(\vec{p}_T^{\,H^+}))^2 = \left(\sqrt{m_{top}^2 + (\vec{p}_T^{\,H^+} + \vec{p}_T^{\,b})^2} - p_T^b\right)^2 - \left(\vec{p}_T^{\,H^+}\right)^2$.

- Assign the leptons and the b jets:
  - check $\cos\theta_l^*$ for the two pairs and remove unphysical pairings ($\cos\theta_l^* > 1$)
  - if both pairings are correct: take the smallest sum of $\Delta R(l,b)_{\text{pair 1}} + \Delta R(l,b)_{\text{pair 2}}$
  - assign the smallest $\cos\theta_l^*$ to the "H^+ side" and the other to the "W side"

$t\bar{t}$ ($bbWW$)	Single top-quark	Z+jets	Diboson	QCD and W+jets	$\sum$ SM	Data	130 GeV H^+ $\mathcal{B}(t \to bH^+) = 10\%$
864	18	1.5	0.3	40	924	992	115

Table 2: Expected and observed number of events with $\int \mathcal{L}dt = 1.03$ fb^{-1}, a fitted value of 150.4 pb is used for σ_{bbWW}.

Limits on the Branching Ratio of $t \to bH^+$

Assuming $\mathcal{B}(H^+ \to \tau\nu) = 1$, upper limits are extracted on the branching ratio $\mathcal{B}(t \to bH^+)$, as a function of the charged Higgs boson mass, using a profile likelihood statistical analysis.

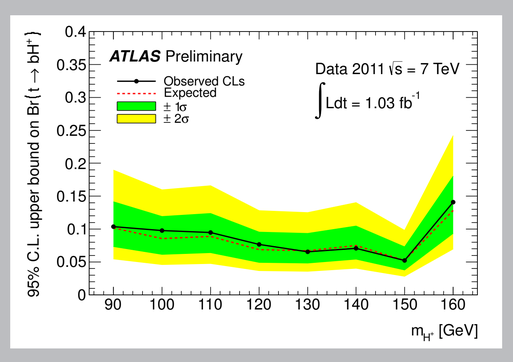

Figure 7: Expected and observed combined upper limits with 95% C.L. as a function of m_{H^+}.

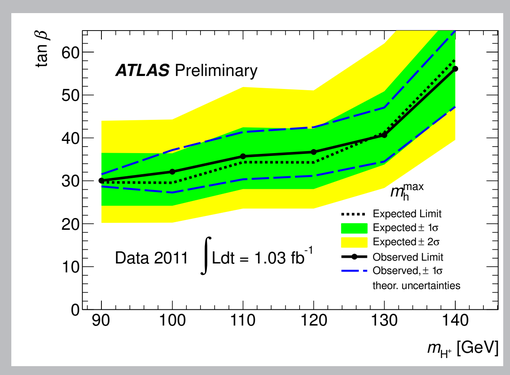

Figure 8: Combined limits for H^+ production in the m_{H^+}-$\tan\beta$ plane (m_H^{max} scenario).

The τ+jets Final State

Multi-jet background estimation and jet-to-τ misidentification probability

The main sources of background in charged Higgs boson searches are coming from processes as:
- $t\bar{t}$ production
- multi-jet events
- single top quark
- W+jets

All are determined with data-driven methods.

Jet$\to\tau$ misidentification probability is measured from γ-jet events for jets with 1 or 3 associated tracks as a function of p_T and η.

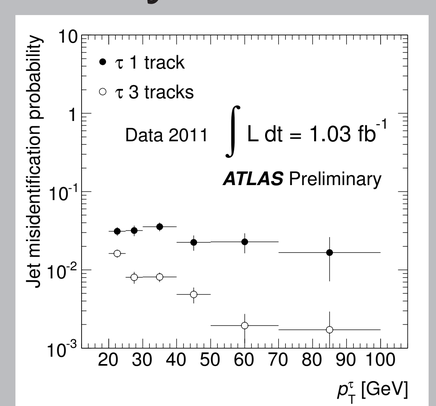

Figure 9: Jet $\to\tau$ misidentification probability.

The multi-jet event estimate is determined by a fit to the E_T^{miss} distribution in data after all selection cuts using two shapes (one for the multi-jet model, and one for all other background processes, dominated by $t\bar{t}$ and W+jets).

- To study this shape in a data-driven way, a control region is defined where the τ identification and b-tagging requirements are inverted.
- The multi-jet event fraction estimated after all selection cuts is $(23 \pm 10)\%$.

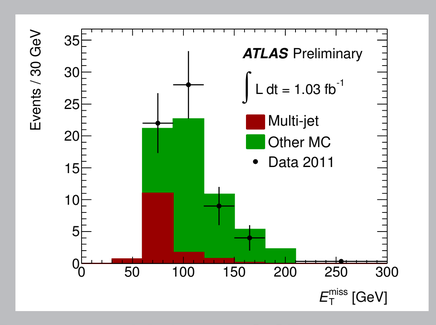

Figure 10: Multi-jet QCD estimation.

The embedding method

To estimate the background from true τ jets an embedding method is used, which consists in collecting a control sample of $t\bar{t}$, single-top, and W+jets events with a muon in data, and replacing the detector signature of this muon with that of a simulated τ lepton.

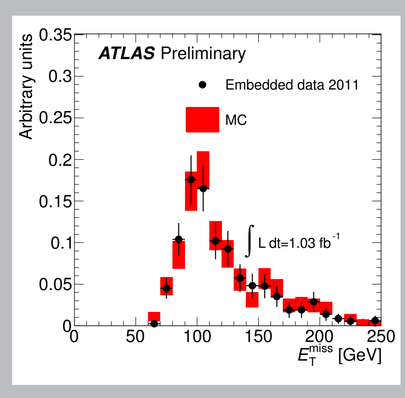

Figure 11: Validation of the embedding method.

- The hybrid event is reconstructed and used to estimate the background to the H^+ selection.
- With the embedding method it is possible to include the underlying event and pile-up, missing energy, b quark jets and light-quark jets from data.

Results and limits

The transverse mass m_T distribution of collision data, and the estimates from data-driven methods are compared.
m_T is defined as:

$$m_T = \sqrt{2p_T^\tau E_T^{miss}(1 - \cos\Delta\phi)}.$$

The expected and observed 95% C.L. exclusion limit for charged Higgs boson production from top quark decays as a function of m_{H^+} is determined.

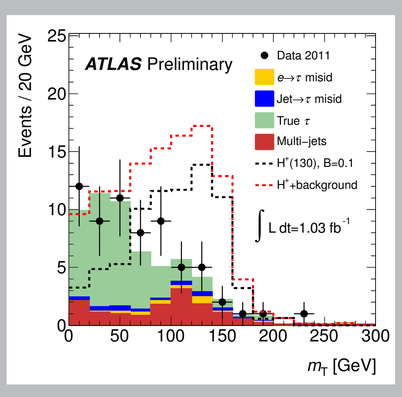

Figure 12: m_T distribution after event selection.

	Events with/from					
	true τ jets	jet $\to\tau$ mis-id	$e\to\tau$ mis-id	multi-jet	expected (sum)	data
$m_T > 40$ GeV	21 ± 5	2.4 ± 0.7	1.9 ± 0.2	12 ± 5	37 ± 7	43

Table 3: Expected and observed number of events with $\int \mathcal{L}dt = 1.03$ fb^{-1}.

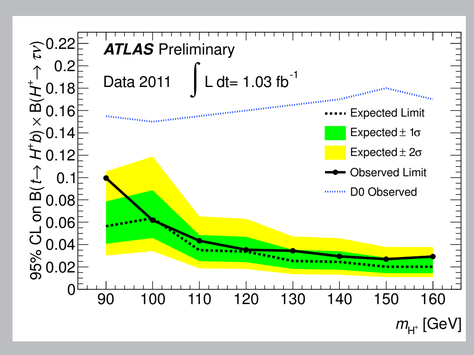

Figure 13: Expected and observed limits with 95% C.L. as a function of m_{H^+}.

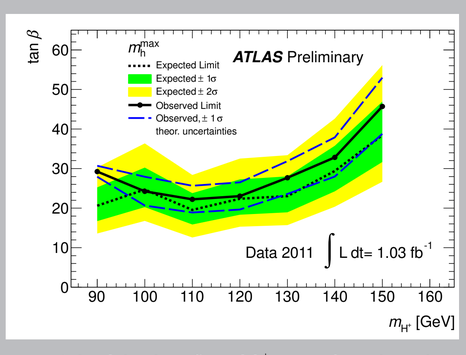

Figure 14: Limits for H^+ production in the m_{H^+}-$\tan\beta$ plane (m_H^{max} scenario).

[1] *Search for a charged Higgs boson $H^+ \to \tau_{lep} + \nu$ in $t\bar{t}$ events with one or two leptons, using 1.03 fb^{-1} of pp collision data recorded at $\sqrt{s} = 7$ TeV with the ATLAS detector*, ATLAS-CONF-2011-151
[2] *Search for Charged Higgs Bosons in the τ+jets Final State in $t\bar{t}$ Decays with 1.03 fb^{-1} of pp Collision Data Recorded at $\sqrt{s} = 7$ TeV with the ATLAS Experiment*, ATLAS-CONF-2011-138