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Search strategies for charged Higgs bosons in ATLAS

Search strategies for charged Higgs bosons in ATLAS

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On behalf of the ATLAS Collaboration

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Introduction

- In the Standard Model (SM), only 1 doublet of Higgs scalars is responsible for the electroweak symmetry breaking: there is only one neutral Higgs boson h^0.
- Other so-called 2HDM models, in particular MSSM, predict the existence of 2 complex Higgs doublets... hence 5 physical states: H^+, H^-, h^0, H^0, A^0.
- The tree level MSSM Higgs sector is fully determined by two independent parameters only: m_{H^+} and $\tan\beta$.

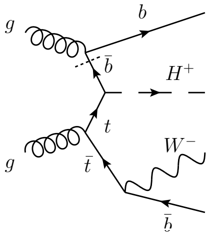
This presentation gives an overview of the ATLAS search strategies for charged Higgs bosons:

- in the high-mass range (above m_t): $\sqrt{s} = 14$ TeV and $\int \mathcal{L}dt > 1$ fb^{-1}.
- in the low-mass range (below m_t): $\sqrt{s} = 7$ TeV and $\int \mathcal{L}dt = 1$ fb^{-1}.

Search for heavy charged Higgs bosons

All results are from CERN-OPEN-2008-020.

Production: $gb \to tH^+$ and $gg \to tbH^+$



Results are presented for two processes:

- $gg/gb \to t[b]H^+ \to bqq[b]\tau_{had}\nu$
- $gg/gb \to t[b]H^+ \to t[b]tb \to b\ell\nu[b]bqqb$

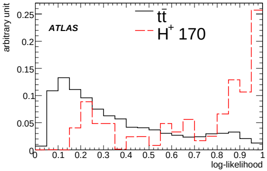
$H^+ \rightarrow \tau_{had}\nu$: event selection

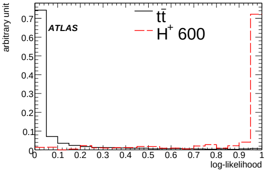
In order to select $gg/gb \rightarrow t[b]H^+ \rightarrow bqq[b]\tau_{had}\nu$:

- Triggers: E_T^{miss} (possibly with multi-jets) + tau,
- One τ-jet with $p_T > 50$ GeV and $E_T^{miss} > 40$ GeV,
- At least three additional jets, one of them b-tagged,
- Veto on e/μ with $p_T > 7$ GeV,
- Reconstruction of a W boson and a top quark.

Only the $t\bar{t} \rightarrow b\bar{b}(qq')(\tau_{had}\nu)$ background survives.

Uncorrelated likelihood approach with 5 variables: $p_T(\tau)$, E_T^{miss}, $\Delta\phi(\tau, E_T^{miss})$, $\sum p_T(jets)$ and $p_T(\tau)/p_T(jet^{hardest}_{non-top})$.

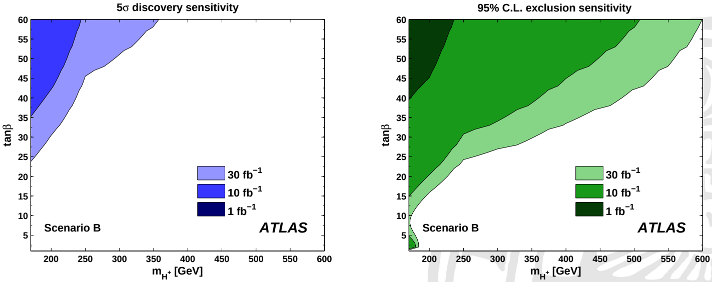




$H^+ \to \tau_{had}\nu$: sensitivity

Discovery and exclusion contours:

Systematic and statistical uncertainties are included. The systematic uncertainty is 44% for the signal, 10% for the background.



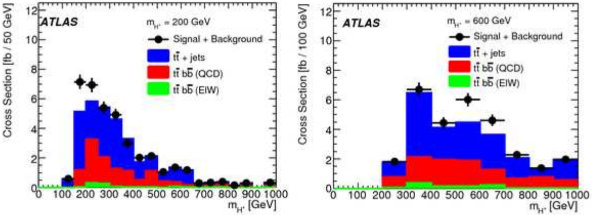
Scenario B = m_h-max

$H^+ \to tb$: event selection

In order to select $gg/gb \to t[b]H^+ \to b\ell\nu[b]bqqb$:

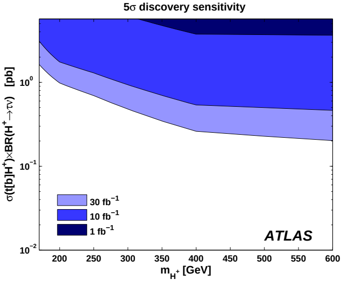
- Triggers: lepton + E_T^{miss}, or multi-jets + E_T^{miss},
- One e/μ with $p_T > 25/20$ GeV and $|\eta| < 2.5$,
- At least 5 jets with $p_T > 20$ GeV and $|\eta| < 5$,
- At least 3 b-tagged jets with $|\eta| < 2.5$,
- Reconstruction of a leptonic W boson,
- Combinatorial likelihood $\mathcal{L}$ to discriminate between correct and wrong combinations of all objects.

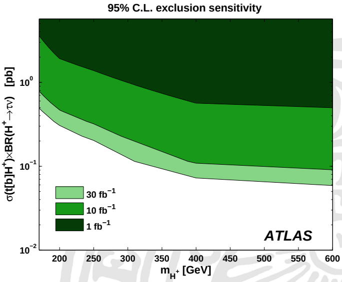
Uncorrelated likelihood approach with 5 variables: $\eta_{b_{H^+}}$, $\sum w_b$, $<\mathcal{L}>$, $\Delta R(b_{H^+}, b_t b_t)$, $p_T(b^{softest}_{non-top})/p_T(b^{hardest}_{non-top})$.



$H^+ \rightarrow tb$: contribution to H^+ sensitivity

No discovery or exclusion power was extracted for this channel on its own, but it contributes to the combined ATLAS sensitivity for charged Higgs bosons.



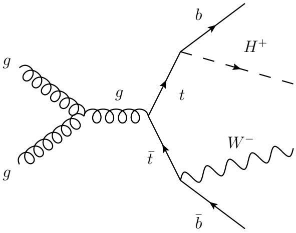


Model-independent contours, with systematic and statistical uncertainties.

Search for light charged Higgs bosons

All results are from ATL-PHYS-PUB-2010-009.

Production: $t\bar{t} \rightarrow b\bar{b}WH^+$



Results are presented for two processes:

- $t\bar{t} \rightarrow b\bar{b}WH^+ \rightarrow b\bar{b}\ell\nu c\bar{s}$
- $t\bar{t} \rightarrow b\bar{b}WH^+ \rightarrow b\bar{b}\ell\nu\tau_{lep}\nu$

$H^+ \to c\bar{s}$: pre-selection cuts

We want to select $t\bar{t} \to b\bar{b}W(l\nu)H^+(c\bar{s})$ events:

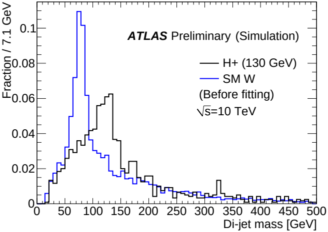
- Single lepton trigger,
- Exactly one electron/muon with $p_T > 20$ GeV and $|\eta| < 2.5$,
- At least four jets with $p_T > 20$ GeV and $|\eta| < 2.5$ (the jet energy is better measured in the central region),
- Two of the four leading jets are *b*-tagged,
- $E_T^{miss} > 20$ GeV.

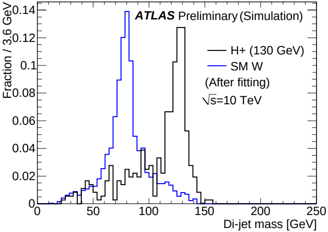
The two non-*b* tagged leading jets are assigned to the dijet system from H^+ (or from W in the case of SM $t\bar{t}$ semileptonic events).

$H^+ \to c\bar{s}$: dijet mass fitter

The dijet mass distributions have a large width and it can be difficult to separate the signal from the background.

More information (and a better dijet mass resolution) are gained by fully reconstructing $t\bar{t}$ semileptonic events.





Kinematical fit with constraints on the $t\bar{t}$ reconstruction: covered by Un-ki Yang's talk.

$H^+ \to c\bar{s}$: cut flow table

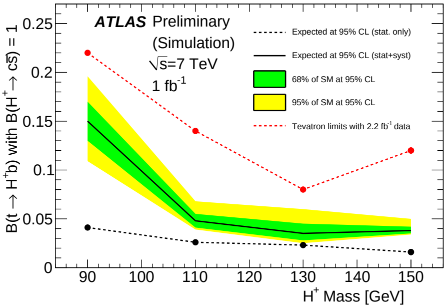
Assuming an integrated luminosity of 1 fb^{-1} and $\mathcal{B}(t \to bH^+) = 10\%$ for the signal:

Process	Expected number of events: no cut	Expected number of events: all cuts
$H^+ \to c\bar{s}$, 90 GeV	9.5×10^3	156
$H^+ \to c\bar{s}$, 110 GeV	9.5×10^3	152
$H^+ \to c\bar{s}$, 130 GeV	9.5×10^3	104
$H^+ \to c\bar{s}$, 150 GeV	9.5×10^3	60
$t\bar{t}$, not all had	87.4×10^3	1430
Single top, Wt	5.7×10^3	18
Single top, t	20.4×10^3	33
Single top, s ($e\nu$)	448	1
Single top, s ($\mu\nu$)	448	1
$Wb\bar{b}$ + jets	5.6×10^3	9
$W \to e\nu$ + jets	39.2×10^3	2
$W \to \mu\nu$ + jets	38.7×10^3	3
$W \to \tau\nu$ + jets	39.0×10^3	0

$H^+ \to c\bar{s}$: upper limits on $\mathcal{B}(t \to bH^+)$

With no signal beyond SM, a binned maximum likelihood method is used to find the upper limit on $\mathcal{B}(t \to bH^+)$ at 95% CL. Systematic uncertainties are taken into account.

m_{H^+} (GeV)	90	110	130	150
Expected upper limit $\mathcal{B}(t \to bH^+)$ (stat. only)	4.0%	2.5%	2.3%	1.5%
Expected upper limit $\mathcal{B}(t \to bH^+)$ (stat + syst)	14.8%	4.7%	3.4%	3.7%



$H^+ \to \tau_{lep}\nu$: new tools for dilepton $t\bar{t}$ events

- The $t\bar{t} \to b\bar{b}WH^+$ events with $W \to \ell\nu_\ell$ & $H^+ \to \tau^+\nu \to l^+\nu\bar{\nu}\nu$ give 6 constraints for 8 variables.

$$\begin{aligned} (p^{H^+} + p^b)^2 &= m_{top}^2 \\ (p^{\ell^-} + p^{\bar{\nu}_\ell})^2 &= m_W^2 \\ (p^{\ell^-} + p^{\bar{\nu}_\ell} + p^{\bar{b}})^2 &= m_{top}^2 \\ (p^{\bar{\nu}_\ell})^2 &= 0 \\ \vec{p}_T^{\,H^+} - \vec{p}_T^{\,l^+} + \vec{p}_T^{\,\bar{\nu}_\ell} &= \vec{p}_T^{\,miss} \end{aligned}$$

$m_{T2}^{H^+}$ is the maximum of $(p^{H^+})^2$ subjected to these constraints.

By construction, $m_{T2}^{H^+} \geq m_{H^+}$: possible discrimination between H^+ and W bosons, based on their masses.

- $\cos\theta_\ell^* \simeq \dfrac{4\, p_b \cdot p_\ell}{m_t^2 - m_W^2} - 1$ is also discriminative.

$$t \to bH^\pm \to b\tau(\to \ell\nu)\nu \neq t \to bW^\pm \to b\ell\nu$$

- p_b and p_ℓ can be chosen in the laboratory frame,
- No knowledge about the momentum of ν_ℓ is required.

$H^+ \rightarrow \tau_{lep}\nu$: event selection

We want to select $t\bar{t} \rightarrow b\bar{b}W(l\nu)H^+(l\nu)$ events:

- Single lepton trigger,
- Two oppositely charged leptons with $p_T > 10$ GeV and $|\eta| < 2.5$,
- One of the charged leptons with $p_T > 20$ GeV,
- At least two jets with $p_T > 15$ GeV and $|\eta| < 5.0$,
- The two jets having the highest *b*-weights are assumed to come from top quark decays.

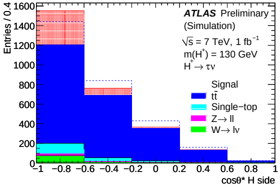
There is a four-fold ambiguity in assigning leptons and *b*-jets to their parents:

- For events with a clear incorrect pairing (unphysical $m_{T2}^{H^+}$ or $\cos\theta_l^*$), the other solution gives the correct *l*-*b* pairs and the smallest $\cos\theta_l^*$ are assigned to H^+,
- For the other events, the pair with the largest $\cos\theta_l^*$ value is assigned to W and its partner pair to H^+.

$H^+ \to \tau_{lep}\nu$: cut flow table

To isolate di-lepton $t\bar{t}$ events with H^+ (presumably):

- b-weight > 4.3,
- $E_T^{miss} > 50$ GeV,
- $\cos\theta_l^* < -0.6$.



Assuming $\int \mathcal{L}dt = 1\ \text{fb}^{-1}$ and $\mathcal{B}(t \to bH^+) = 10\%$:

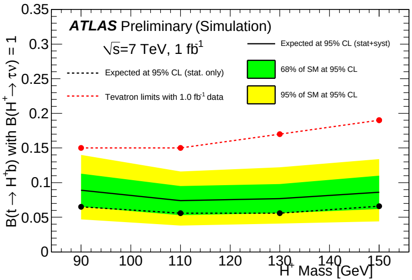
Process	Expected number of events no cut	Expected number of events all cuts
$H^+ \to \tau\nu$, 90 GeV	2.5×10^3	282
$H^+ \to \tau\nu$, 110 GeV	2.5×10^3	330
$H^+ \to \tau\nu$, 130 GeV	2.5×10^3	326
$H^+ \to \tau\nu$, 150 GeV	2.5×10^3	284
$t\bar{t}$, not all had	87.3×10^3	1194
Single top, Wt	5.7×10^3	55
Single top, t	20.4×10^3	43
Single top, s	0.9×10^3	3
$Wb\bar{b}$ + jets	8.7×10^3	12
$Zb\bar{b}$ + jets	2.8×10^4	11
$W \to \ell\nu$ + jets	3.2×10^7	4
$Z \to \ell\ell$ + jets	3.1×10^6	42

$H^+ \to \tau_{lep}\nu$: upper limits on $\mathcal{B}(t \to bH^+)$

With no signal beyond SM, $\mathcal{B} = \dfrac{N_{\rm obs} - N_{\rm bg}}{2 \times \sigma_{t\bar{t}} \times \mathcal{L}_{int} \times \epsilon_{\rm sig}}$.

The 95% CL upper limit are then extracted, based on pseudo-experiments taking into account uncertainties on $N_{\rm obs}$, $N_{\rm bg}$ and $\epsilon_{\rm sig}$.

Mass (GeV)	Expected upper limit on $\mathcal{B}(t \to bH^+)$ without systematics	with systematics
90	6.5%	8.9%
110	5.6%	7.4%
130	5.6%	7.4%
150	6.6%	8.6%



Conclusion

The search for charged Higgs bosons in ATLAS has just started! During the early data-taking period (2010-2011), light charged Higgs bosons are searched for in $t\bar{t}$ events:

- $t\bar{t} \to b\bar{b}WH^+ \to b\bar{b}\ell\nu c\bar{s}$
- $t\bar{t} \to b\bar{b}WH^+ \to b\bar{b}\ell\nu\tau_{lep}\nu$

Several other channels (not presented here) are also considered:

- $t\bar{t} \to b\bar{b}WH^+ \to b\bar{b}qq'\tau_{lep}\nu$
- $t\bar{t} \to b\bar{b}WH^+ \to b\bar{b}qq'\tau_{had}\nu$
- $t\bar{t} \to b\bar{b}WH^+ \to b\bar{b}\ell\nu\tau_{had}\nu$
- ratio method: search for an apparent violation of lepton universality in top decays due to $H^+ \to \tau\nu$.

Sensitivity studies suggest that ATLAS will bring down the upper limits on $\mathcal{B}(t \to bH^+)$ from Tevatron + we will learn a lot for (future) heavy charged Higgs boson searches.