Charged Higgs boson searches in the ATLAS experiment

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On behalf of the ATLAS collaboration

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Outline

1 Introduction

2 $H^+ \rightarrow c\bar{s}$

3 $H^+ \rightarrow \tau_{had}\nu$

4 Conclusion
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Introduction

1. Introduction

2. $H^+ \rightarrow c\bar{s}$

3. $H^+ \rightarrow \tau_{had}\nu$

Conclusion

4. Conclusion
Theoretical background

- 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:
  - One Higgs mass: $m_A$ or $m_{H^+} = \sqrt{m_A^2 + m_W^2}$,
  - The ratio of the vacuum expectation values of the Higgs doublets, $\tan \beta$.

In the low mass range, assuming no charged Higgs boson decay into supersymmetric particles:
- $H^+ \rightarrow \tau \nu$ dominates below the $tb$ threshold,
- $H^+ \rightarrow c\bar{s}$ may have a significant branching fraction at low $\tan \beta$. 
Light charged Higgs bosons at the LHC

Production of light charged Higgs bosons at the LHC: $t\bar{t} \rightarrow b\bar{b}WH^+$ (and $t\bar{t} \rightarrow b\bar{b}H^+H^-$ to a lower extent).

Copious production of $t\bar{t}$ pairs: $\sigma_{t\bar{t}} = 164.6$ pb (NNLO).

Results are presented for two processes:

- $t\bar{t} \rightarrow b\bar{b}WH^+ \rightarrow b\bar{b}\ell\nu c\bar{s}$
- $t\bar{t} \rightarrow b\bar{b}WH^+ \rightarrow b\bar{b}qq'\tau_{\text{had}}\nu$
Charged Higgs boson searches in the ATLAS experiment

Introduction

**H**^+ → **c**ς

**H**^+ → **τ**_{had}ν

Data collection at the LHC in 2010 and 2011

Only data taken with all ATLAS subsystems operational are used for our analyses: 35 pb\(^{-1}\) in 2010, and 1 fb\(^{-1}\) in 2011 (until the June-July technical stop).

The LHC instantaneous luminosity is now above 2 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}.

With high luminosity comes pile-up! \langle \mu \rangle = 5.7 \rightarrow
The ATLAS experiment

Charged Higgs boson searches require the full potential of the ATLAS detector:

- electrons,
- muons,
- jets, including $b$-tagging,
- $\tau$-jets,
- missing $E_T$,
- triggers: lepton or $\tau + E_T^{miss}$.
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Introduction

$H^+ \rightarrow c\bar{s}$: event selection & dijet mass fitter

Cuts are applied to select $t\bar{t} \rightarrow b\bar{b}W(l\nu)H^+(c\bar{s})$, i.e. one high-$p_T$ charged lepton, at least four jets and large $E_T^{miss}$.

Two (non-$b$ tagged) jets are assigned to the dijet system from $H^+$ (or from $W$ in the case of SM $t\bar{t}$ events). These dijet mass distributions have a large width and it can be difficult to separate the signal from the background.

Better dijet mass resolution when reconstructing the $t\bar{t}$ semi-leptonic events with a kinematic fit.

![Di-jet Mass Distribution](image)
$H^+ \rightarrow c\bar{s}$: results with 35 pb$^{-1}$

- The event yield agrees with the SM expectations,
- The background consists mostly of SM $t\bar{t}$ events (80%) and QCD was estimated from data.

The presence of $H^+ \rightarrow c\bar{s}$ would appear as a depletion of the $W$ peak and as a second peak. None of them is observed.

<table>
<thead>
<tr>
<th>Channel</th>
<th>Muon</th>
<th>Electron</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data</td>
<td>193</td>
<td>130</td>
</tr>
<tr>
<td>SM $t\bar{t} \rightarrow W^+ b W^- \bar{b}$</td>
<td>$156^{+24}_{-29}$</td>
<td>$106^{+16}_{-20}$</td>
</tr>
<tr>
<td>$W/Z +$ jets</td>
<td>$17 \pm 6$</td>
<td>$9 \pm 3$</td>
</tr>
<tr>
<td>Single top</td>
<td>$7 \pm 1$</td>
<td>$5 \pm 1$</td>
</tr>
<tr>
<td>Diboson</td>
<td>$0.30 \pm 0.02$</td>
<td>$0.20 \pm 0.02$</td>
</tr>
<tr>
<td>QCD multijet</td>
<td>$11 \pm 4$</td>
<td>$6 \pm 3$</td>
</tr>
<tr>
<td>Total Expected (SM)</td>
<td>$191^{+26}_{-30}$</td>
<td>$127^{+17}_{-21}$</td>
</tr>
<tr>
<td>$\mathcal{B}(t \rightarrow H^+ b) = 10%$ :</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$t\bar{t} \rightarrow H^+ b W^- \bar{b}$</td>
<td>$20^{+3}_{-4}$</td>
<td>$14^{+2}_{-3}$</td>
</tr>
<tr>
<td>$t\bar{t} \rightarrow W^+ b W^- \bar{b}$</td>
<td>$127^{+19}_{-23}$</td>
<td>$86^{+13}_{-16}$</td>
</tr>
<tr>
<td>Total Expected ($\mathcal{B} = 10%$)</td>
<td>$181^{+21}_{-25}$</td>
<td>$120^{+14}_{-17}$</td>
</tr>
</tbody>
</table>
$H^+ \rightarrow c\bar{s}$: upper limits on $B(t \rightarrow bH^+)$

Major systematic uncertainties:
* Jet energy scale (9-13%) & $b$-tagging efficiency (4-9%),
* Top quark mass and production cross section (7-9%).

Limits are extracted by finding the branching fraction for which the confidence level in the signal hypothesis (CLs) reaches 0.05:

First LHC results on $H^+ \rightarrow c\bar{s}$, competitive with Tevatron results with only 35 pb$^{-1}$!
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\[ H^+ \rightarrow \tau_{had} \nu: \text{ event selection} \]

Search for \( \bar{t}t \rightarrow b\bar{b}WH^+ \rightarrow b\bar{b}(qq')(\tau_{had}\nu) \) events:

1. \( E_T^{\text{miss}} + \tau \) trigger with thresholds of 35 and 29 GeV, respectively,
2. At least 4 jets with \( p_T > 20 \) GeV and \( |\eta| < 2.5 \),
3. Exactly 1 trigger-matched \( \tau \)-jet with \( p_T > 35 \) GeV and \( |\eta| < 2.3 \),
4. Veto events with electrons having \( E_T > 20 \) GeV or muons having \( p_T > 10 \) GeV,
5. \( E_T^{\text{miss}} > 40 \) GeV and \( \frac{E_T^{\text{miss}}}{0.5 \sqrt{\sum E_T}} > 8 \) GeV\(^{1/2} \),
6. At least one \( b \)-tagged jet,
7. The \( qqb \) candidate with the highest \( p_T^{qqb} \) must have its mass between 120 and 240 GeV.

Discriminating variable: \( m_T = \sqrt{2p_T^{\tau}E_T^{\text{miss}}(1 - \cos \phi_{\tau, \text{miss}})} \)
$H^+ \rightarrow \tau_{had}\nu$: background estimation (1)

The main backgrounds to $t\bar{t} \rightarrow b\bar{b}WH^+ \rightarrow b\bar{b}(qq')(\tau_{had}\nu)$ can be determined in a data-driven way:

- Events with an electron misidentified as a $\tau$,
- Events with a quark misidentified as a $\tau$,
- Events with QCD jets,
- Events with true $\tau$ jets.

Measurement of $\tau$ misidentification probabilities in data:

- Tag-and-probe method on $Z/\gamma^* \rightarrow ee$ for electrons,
- Use inclusive $\gamma$-jet events for quarks.

After comparison with MC misidentification probabilities, scale factors are computed to correct the prediction from simulations.
**$H^+ \rightarrow \tau_{had} \nu$: background estimation (2)**

**QCD background estimation in data:**

- Define a control region by using all event selection cuts, but requesting a loose $\tau$ and no $b$-jet.
- The QCD shape of $E_T^{miss}$ and $m_T$ are assumed to be the same in the signal and control regions.
- The QCD fraction is derived from data using $E_T^{miss}$ in the control region: $f_{QCD} = (23 \pm 10)\%$ [the non-QCD processes are simulated].

Using the $m_T$ distribution and the QCD fraction from the control region, the QCD $m_T$ distribution is estimated in the signal region.

![Graph showing QCD background estimation](graph.png)
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Introduction

$H^+ \rightarrow \tau_{had} \nu$: background estimation (3)

Background with true $\tau$ jets $\rightarrow$ embedding:

- Collect a control sample of data $t \bar{t}$, single top and $W+$jets with a muon,
- Replace the detected muon with a simulated $\tau$,
- Re-apply the reconstruction with the signal event selection,
- Normalize to data in the range $m_T < 40$ GeV.

ATLAS Preliminary

- Embedded data 2011
- MC

ATLAS Preliminary

- Embedded data 2011
- MC

ATLAS Preliminary

- Embedded data 2011
- MC

ATLAS Preliminary

- Embedded data 2011
- MC

Conclusion
$H^+ \to \tau_{had}\nu$: results with 1 fb$^{-1}$

Good agreement between estimated and observed number of events in the range $m_T > 40$ GeV.

Dashed lines $\rightarrow 130$ GeV $H^+$ with $\text{Br}(t \to bH^+)=10\%$ and $\text{Br}(H^+ \to \tau\nu)=100\%$
\( H^+ \rightarrow \tau_{had} \nu \): upper limits on \( B(t \rightarrow bH^+) \)

Branching fractions \( B(t \rightarrow bH^+)B(H^+ \rightarrow \tau \nu) > 3 - 10\% \) are excluded in the \( H^+ \) mass range 90-160 GeV.

Interpreted in the context of the mh-max scenario of the MSSM, tan \( \beta \) values above 22-30 can be excluded in the \( H^+ \) mass range 90-140 GeV.
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Summary and outlook

Summary:
- With 35 pb$^{-1}$, ATLAS is competitive with the Tevatron results for the exclusion of $H^+ \rightarrow c\bar{s}$,
- With 1 fb$^{-1}$, ATLAS has excluded $H^+ \rightarrow \tau_{had}\nu$ in the $H^+$ mass range 90-160 GeV, for branching fractions $\mathcal{B}(t \rightarrow bH^+)\mathcal{B}(H^+ \rightarrow \tau\nu) > 3 - 10\%$,

Outlook:
With more data delivered by the LHC (> 2.5 fb$^{-1}$), ATLAS is likely to exclude a wider range of $\mathcal{B}(t \rightarrow bH^+)$, or make a discover of the light charged Higgs boson!

An analysis of the $H^+ \rightarrow \tau_{lep}\nu$ events in the $H^+$ mass range 90-160 GeV is on-going, based on advanced discriminating variables.

Eventually look for charged Higgs bosons above the $tb$ threshold.