Charged Higgs boson searches in the ATLAS experiment

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Outline

1. Introduction
2. $H^+ \to c\bar{s}$
3. $H^+ \to \tau_{had}\nu$
4. Conclusion

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Charged Higgs boson searches in the ATLAS experiment

Theoretical background

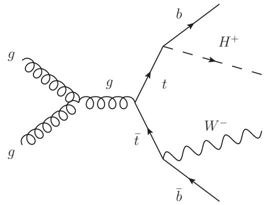
- In the Standard Model (SM), only 1 doublet of Higgs scalars is responsible for the electroweak symmetry breaking: there is only one neutral Higgs boson h^0.
- Other so-called 2HDM models, in particular MSSM, predict the existence of 2 complex Higgs doublets... hence 5 physical states: H^+, H^-, h^0, 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:

- $H^+ \to \tau\nu$ dominates below the tb threshold,
- $H^+ \to c\bar{s}$ 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: $t\bar{t} \to b\bar{b}WH^+$ (and $t\bar{t} \to b\bar{b}H^+H^-$ 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:

- $t\bar{t} \to b\bar{b}WH^+ \to b\bar{b}\ell\nu c\bar{s}$
- $t\bar{t} \to b\bar{b}WH^+ \to b\bar{b}qq'\tau_{had}\nu$

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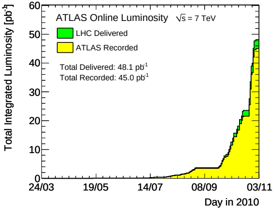
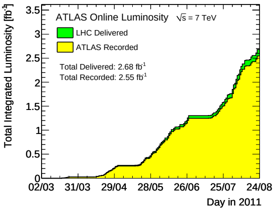
Charged Higgs boson searches in the ATLAS experiment

Data collection at the LHC in 2010 and 2011

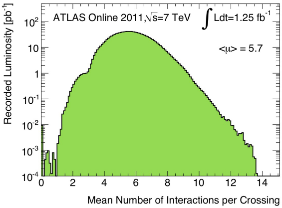
Only data taken with all ATLAS subsystems operational are used for our analyses: 35 pb^{-1} in 2010, and 1 fb^{-1} in 2011 (until the June-July technical stop).





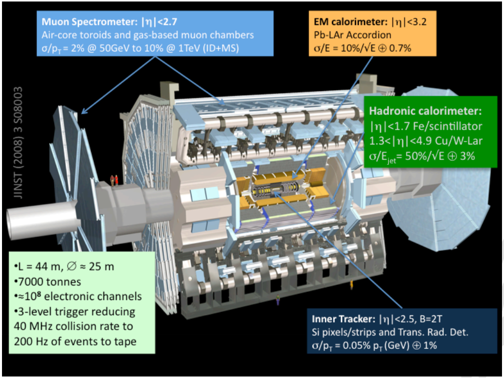
The LHC instantaneous luminosity is now above $2 \times 10^{33}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$.

With high luminosity comes pile-up! $< \mu >= 5.7 \longrightarrow$



The ATLAS experiment

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



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

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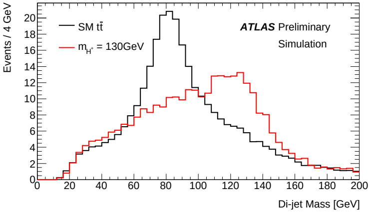
Charged Higgs boson searches in the ATLAS experiment

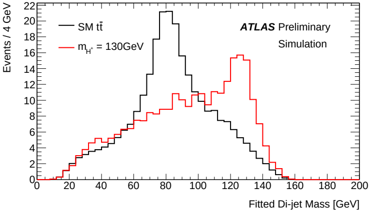
$H^+ \to c\bar{s}$: event selection & dijet mass fitter

Cuts are applied to select $t\bar{t} \to b\bar{b}W(l\nu)H^+(c\bar{s})$, 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.



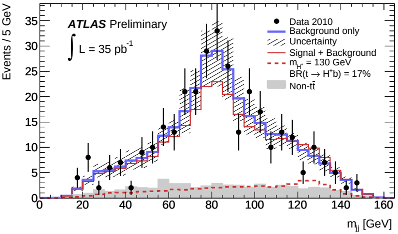


$H^+ \to c\bar{s}$: results with 35 pb^{-1}

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

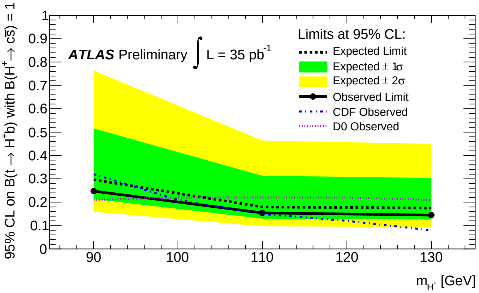
Channel	Muon	Electron
Data	193	130
SM $t\bar{t} \to W^+bW^-\bar{b}$	156^{+24}_{-29}	106^{+16}_{-20}
W/Z + jets	17 ± 6	9 ± 3
Single top	7 ± 1	5 ± 1
Diboson	0.30 ± 0.02	0.20 ± 0.02
QCD multijet	11 ± 4	6 ± 3
Total Expected (SM)	191^{+26}_{-30}	127^{+17}_{-21}
$\mathcal{B}(t \to H^+b) = 10\%$:		
$t\bar{t} \to H^+bW^-\bar{b}$	20^{+3}_{-4}	14^{+2}_{-2}
$t\bar{t} \to W^+bW^-\bar{b}$	127^{+19}_{-23}	86^{+13}_{-16}
Total Expected ($\mathcal{B}$ = 10%)	181^{+21}_{-25}	120^{+14}_{-17}



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

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 $H^+ \to c\bar{s}$, competitive with Tevatron results with only 35 pb^{-1}!

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

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

1. $E_T^{miss} + \tau$ 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 τ-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. $E_T^{miss} > 40$ GeV and $\frac{E_T^{miss}}{0.5\sqrt{\sum E_T}} > 8\ \text{GeV}^{1/2}$,
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: $m_T = \sqrt{2p_T^{\tau}E_T^{miss}(1 - \cos\phi_{\tau,miss})}$

$H^+ \to \tau_{had}\nu$: background estimation (1)

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

- Events with an electron misidentified as a τ,
- Events with a quark misidentified as a τ,
- Events with QCD jets,
- Events with true τ jets.

Measurement of τ misidentification probabilities in data:

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

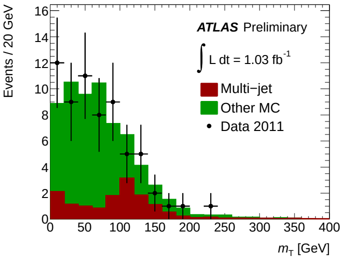
After comparison with MC misidentification probabilities, scale factors are computed to correct the prediction from simulations.

$H^+ \to \tau_{had}\nu$: background estimation (2)

QCD background estimation in data:

- Define a control region by using all event selection cuts, but requesting a loose τ 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].

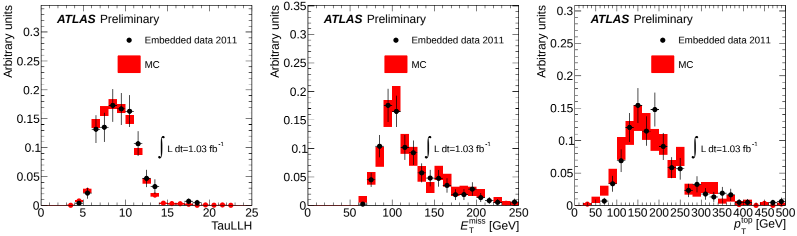
Using the m_T distribution and the QCD fraction from the control region, the QCD m_T distribution is estimated in the signal region.



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

Background with true τ jets $\to$ 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 τ,
- Re-apply the reconstruction with the signal event selection,
- Normalize to data in the range $m_T < 40$ GeV.

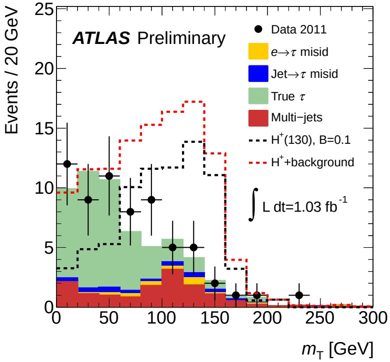


$H^+ \to \tau_{had}\nu$: results with 1 fb^{-1}

	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

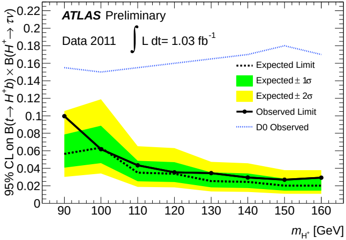
Good agreement between estimated and observed number of events in the range $m_T > 40$ GeV.

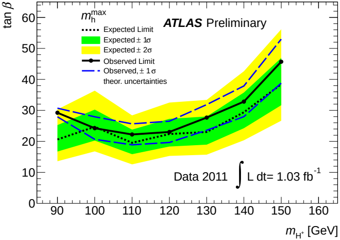
Dashed lines $\to$ 130 GeV H^+ with Br($t \to bH^+$)=10% and Br($H^+ \to \tau\nu$)=100%



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

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





Interpreted in the context of the mh-max scenario of the MSSM, tan β 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 $H^+ \to c\bar{s}$,
- With 1 fb^{-1}, ATLAS has excluded $H^+ \to \tau_{had}\nu$ in the H^+ mass range 90-160 GeV, for branching fractions $\mathcal{B}(t \to bH^+)\mathcal{B}(H^+ \to \tau\nu) > 3 - 10\%$,

Outlook:

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

An analysis of the $H^+ \to \tau_{lep}\nu$ 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.