Searching for charged Higgs bosons with ATLAS

Joakim Gradin

LPSC Grenoble & Uppsala University

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  - theory & phenomenology
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- The Higgs boson - the last piece of the puzzle...

Higgs bosons(s?)

- The **Standard Model** covers a whole lot of physics.
- The Higgs boson - the last piece of the puzzle...

- ...but have we got the **full** piece?

- Why is the Higgs mass observed as 125 GeV?

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- **Supersymmetry** can solve this problem...
- ...but can't work with only one Higgs.
- Many shortcomings of the SM are manifested in the results **cosmological** experiments.
- Two Higgs doublet models can generate baryon asymmetry.

Higgs boson(s?)

The heart of the matter in the "**Brout-Englert-Higgs** mechanism" are the gauge field couplings and the subsequent symmetry breaking. Whatever does the trick is good.

$$\mathcal{L}_{QED} = i\bar{\Psi}\gamma^{\mu}\mathcal{D}_{\mu}^{\Psi}\Psi - m\bar{\Psi}\Psi + (\mathcal{D}_{\mu}^{\Phi}\Phi)^{\dagger}(\mathcal{D}^{\Phi\mu}\Phi) - \mathcal{V}(\Phi) - \frac{1}{4}\mathcal{F}_{\mu v}\mathcal{F}^{\mu v} \quad (2)$$

Occam's razor: the simplest model (SM) produces one extra boson.

$$\Phi = \begin{pmatrix} \phi^{+} \\ \phi^{0} \end{pmatrix} = \frac{1}{\sqrt{2}} \begin{pmatrix} \sqrt{2}W^{+} \\ v + H + iZ^{0} \end{pmatrix} \quad (3)$$

Why keep it "simple"? Put **two** doublets in!

$$\Phi_1 = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix} = \frac{1}{\sqrt{2}} \begin{pmatrix} \sqrt{2}(W_L^+ \cos\beta - H^+ \sin\beta) \\ v\cos\beta - h\sin\alpha + H\cos\alpha + i(Z_L^0 \cos\beta - A\sin\beta) \end{pmatrix} \quad (4)$$

$$\Phi_2 = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix} = \frac{1}{\sqrt{2}} \begin{pmatrix} \sqrt{2}(W_L^+ \sin\beta + H^+ \cos\beta) \\ v\sin\beta + h\cos\alpha + H\sin\alpha + i(Z_L^0 \sin\beta + A\cos\beta) \end{pmatrix} \quad (5)$$

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A whole family of Higgses! With the SM like light neutral scalar.

In a **2HDM**, e.g. the **MSSM**, a charged Higgs boson will...

- ...couple to fermions similar to the W boson.
- ...couple to the h, H, A, W and Z.
- ...have coupling constants that can be parameterized by

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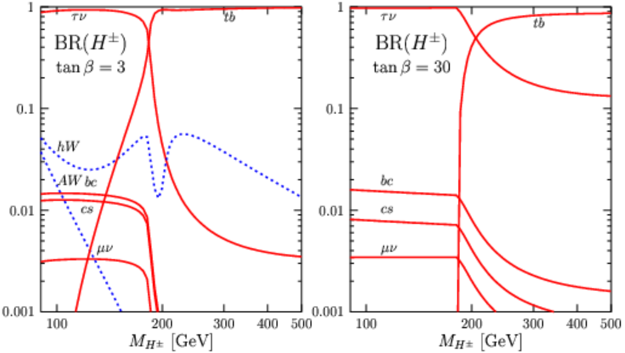
- **Type I**: One doublet couples to the vector bosons, the other to the fermions.
- **Type II**: One doublet couples to up-quarks , the other to down-quarks.
- **Lepton specific**: As I but leptons couple to both doublets.
- **Flipped**: As II but leptons only couples to one doublet.

Charged Higgs decays

The branching ratios of th H^+ depends greatly on the model/type. Some general features are...

- ...favors **heavy** particles, i.e. t, b, τ et.c.
- ...can be classified in **two regimes**:
  - Heavy $m_{H^+} > m_t$
  - Light $m_{H^+} < m_t$

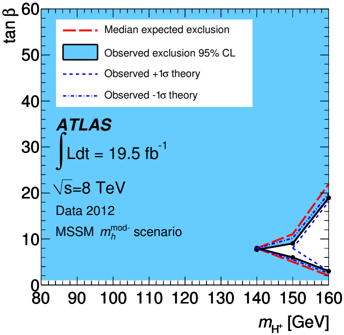


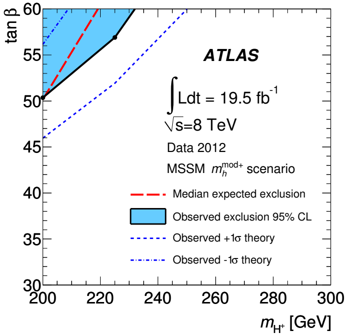
- The SM Higgs boson was hard enough to find.
- A charged Higgs has many more places to hide.
- Indirect searches (LHCb, BELLE, BaBar,..)
- Direct searches (**ATLAS**, CMS,...)

- Run I analyses
  - $H^+ \to \tau\nu$
  - $H^+ \to c\bar{s}$
  - $H^+ \to W^{\pm}Z$
  - $H^+ \to tb$
    - **top associated production**
    - s-channel with boosted all-hadronic.
- Run II analyses
  - $H^+ \to tb$
  - $H^+ \to \tau\nu$
  - ...

ATLAS H^+ searches

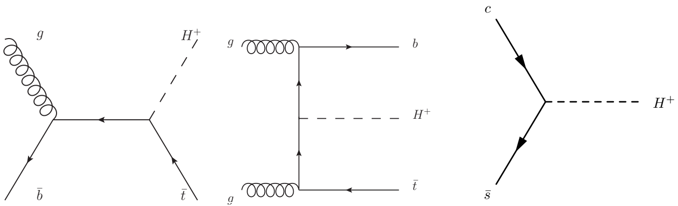
- A light H^+ has been largely excluded.
- We shift our focus to heavy mass regions and boosted topologies.





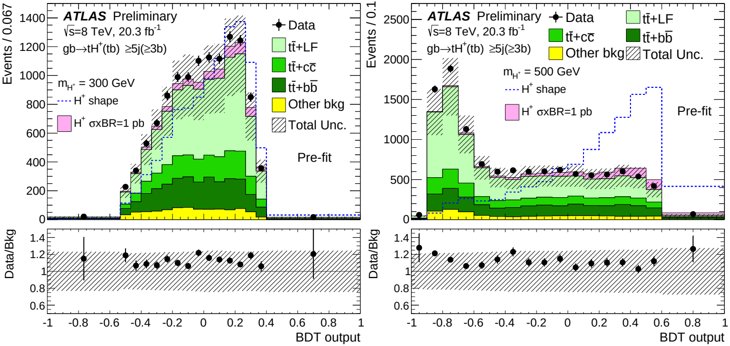
$H^+ \to tb$

- Our signature includes 5 jets with 3 b-tagged jets.
- Bckgrounds:
  - $t\bar{t}$
  - Z/W+jets
  - Singletop
  - ttZ/W/H
  - Multi-jet events.
- The largest background is $t\bar{t}$ with $t\bar{t} + bb$ being highly correlated with our signal.



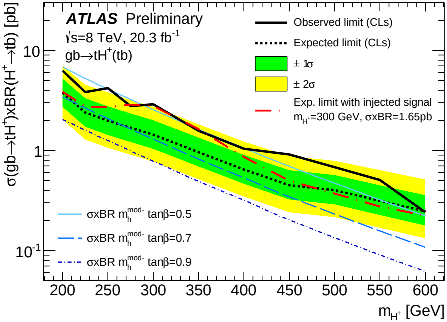
5FS, 4FS top-associated and s-channel production.

- We trained a BDT for each masspoint.
- We use a binned maximum likelihood fit.
- The BDT output and the H_T^{had} is fit in the signal and background regions simultaneously.



- Input variables for the BDT
  - Scalar sum of pT (H_T^{had}).
  - The pT of the leading jet.
  - Invariant mass of the two b-jets closest in ΔR.
  - Second Fox-Wolfram moment.
  - Average ΔR of all b-jet pairs.
- The BDT was found to give best sensitivity and reduction of correlations if trained against $tt + bb$.

- We observe an excess of data for all masspoints but 600 GeV.
- The broad excess is not consistent with any injected signal.
- Paper submitted to JHEP, preprint on arXiv.



- We have large uncertainties on $t\bar{t} + HF$ normalizations and shapes.
- The excess is seen pre-fit and if one uses the BDT trained against the full background or only H_T^{had}
- The $ttH(H \rightarrow bb)$ analysis had a similar result, which shares the same final states.

$H^+ \to tb$ in Run II

- Higher collision energy
  - σ_{tH^+} scales faster with energy than $\sigma_{t\bar{t}}$, 6:4 at 400 GeV.
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- We are including the dilepton final state.
  - A cleaner final state.
  - Boosts our sensitivity.
  - Early studies showed significantly higher $S/\sqrt{B}$, especially at lower mass points.
  - At this moment I am working on finding discriminating variables for the BDT.

Intrested?

- We are a small analysis group.
- We have plenty of tasks for any new persons.
- Now is a really good time to join the effort as we switch gears to prepare the run II analysis.
- Not in ATLAS? Come to the cHarged conferance in Uppsala in september!

Conclusions

- Charged Higgs bosons are part of many BSM theories.
- Light H^+ are mostly excluded.
- Run II will be a very good time to look for heavy H^+
- New exciting experimental methods to develop.

Thanks for listening!

Backup