Charged Higgs boson searches with the ATLAS detector

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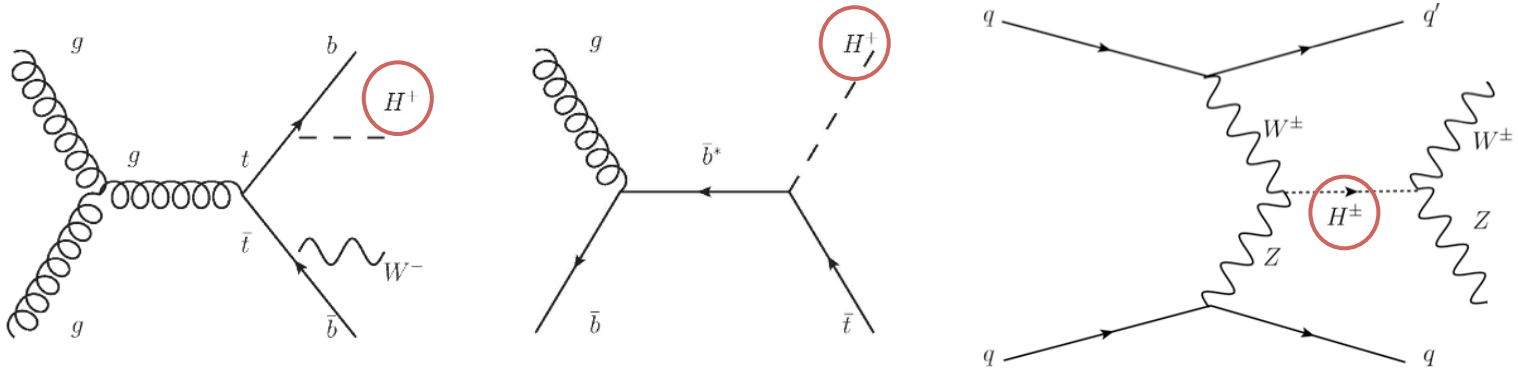


SUSY 2015 Lake Tahoe, California, August 23-29, 2015

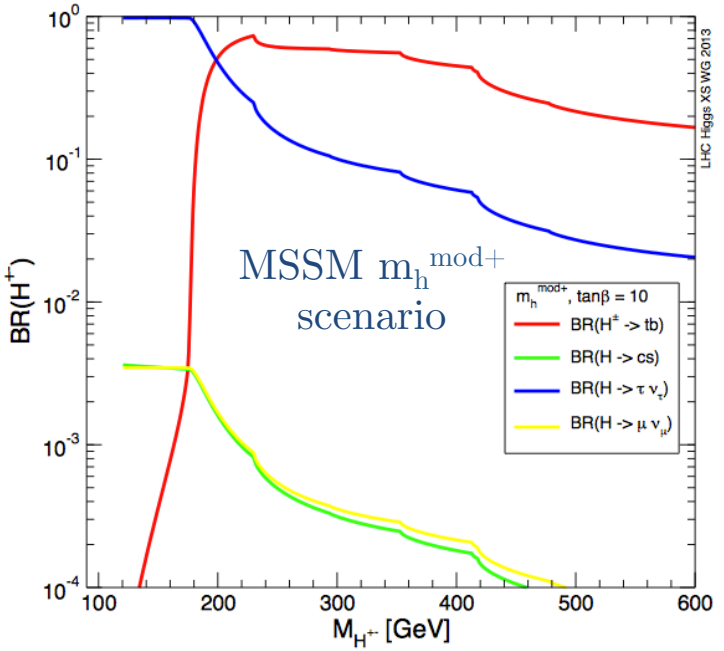
23rd International Conference on Super-symmetry and Unification of Fundamental Interactions

Introduction

- Many extensions of the SM have more than one Higgs boson
  - Ex : Two Higgs Doublet Models (2HDMs)
    - Two complex Higgs doublets $\longrightarrow$ 5 physical states:
      h^0 (light neutral CP even), H^0 (heavy neutral CP even), A (CP odd), $H^{\pm}$
    - MSSM is specific type-II 2HDM (at tree level)
  - Ex : Higgs Triplet Models (Georgi-Machacek Model)
    - Use complex triplet instead of doublet: h^0, $H^{\pm}$, $H^{\pm\pm}$
    - Explain neutrino masses and mixing

H^+ boson is an important feature for BSM Higgs models

- Main H^+ productions at LHC
  - top-quark decays $t \longrightarrow bH^+$ ($m_{H^+} < m_{top}$)
  - Associated prod. with top-quark ($m_{H^+} > m_{top}$)
  - Vector Boson Fusion (Higgs Triplet Models)
- Several decay channels



H^+ boson searches in ATLAS

Interpreted in MSSM

- $H^\pm \longrightarrow \tau^\pm \nu$ in fully hadronic final states
  JHEP 03 (2015) 088 - 19.5 fb^{-1} @ 8TeV
  JHEP 06 (2012) 039 - 4.8 fb^{-1} @ 7TeV
- $H^\pm \longrightarrow \tau^\pm \nu$ via violation of lepton universality in top decays
  JHEP 03 (2013) 076 - 4.8 fb^{-1} @ 7TeV
- $H^\pm \longrightarrow c\bar{s}$ in top decays
  Eur. Phys. J. C, 73 6 (2013) 2465 - 4.8 fb^{-1} @ 7TeV
- $H^\pm$ search through multi-Higgs boson cascade decays
  Phys. Rev. D 89, 032002 (2014) - 19.5 fb^{-1} @ 8TeV

Interpreted in Higgs Triplet Models

- $H^\pm \longrightarrow W^\pm Z$ in Vector Boson Fusion (VBF)
  Phys. Rev. Lett. 114, 231801 (2015) - 19.5 fb^{-1} @ 8 TeV

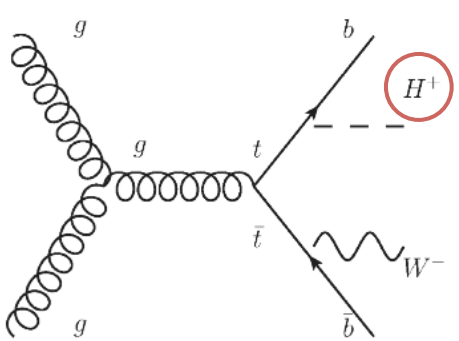
Search for $H^{\pm} \longrightarrow \tau^{\pm}\nu$

JHEP 03 (2015) 088 - 19.5 fb^{-1} @ 8TeV

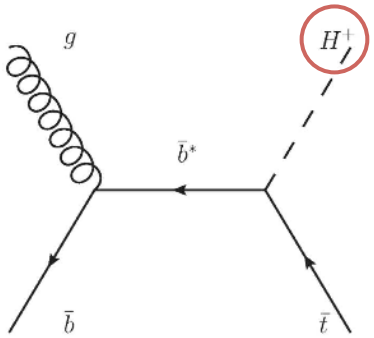
Search for $H^{\pm} \longrightarrow \tau^{\pm}\nu$

JHEP 03 (2015) 088 - 19.5 fb^{-1} @ 8TeV

- Search for $H^{\pm} \longrightarrow \tau^{\pm}\nu$ in fully hadronic final states
  - Dominant in MSSM, for $m_{H^{\pm}} < m_{top}$ and $\tan\beta > 2$, sizeable for $1 < \tan\beta < 2$
  - Still significant at higher mass, especially for large $\tan\beta$
- Model independent approach
  - Different final states analysed for low-mass and high-mass searches



Low-mass H^{+} production
$m_{H^{+}} \in [80,160]$ GeV



High-mass H^{+} production
$m_{H^{+}} \in [180,1000]$ GeV

Signature

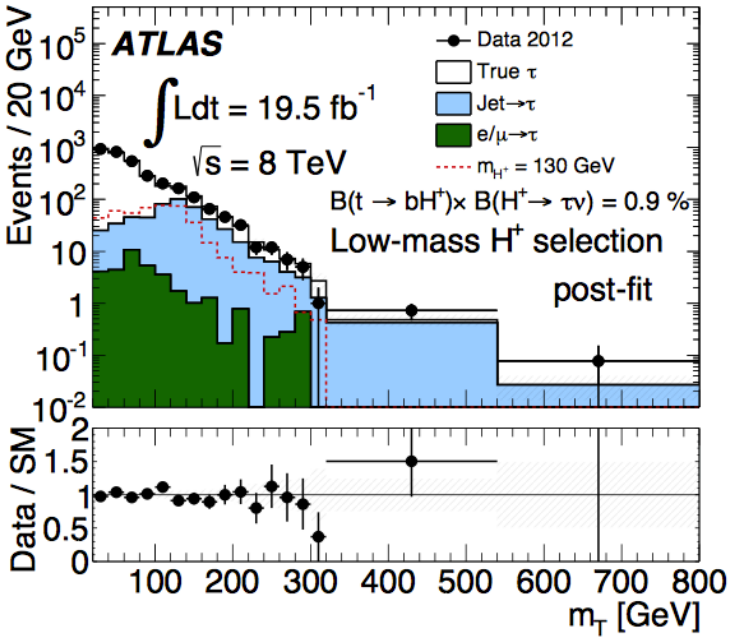
- At least 4 (3) jets for low(high)-mass
  - At least 1 b-tagged jets (70% flavor tagging eff.)
  - Hadronic W boson decay
- Exactly one τ_{had} lepton
- $E_T^{miss} > 65(80)$ GeV for low(high)-mass

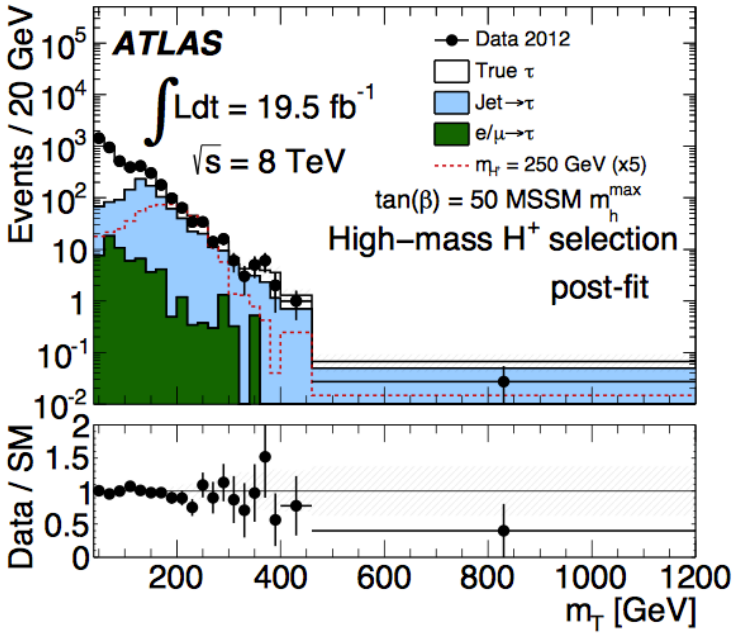
NB : Signal acceptance between 0.3-0.6 % for low-mass and 1.7-5.8 % for high-mass

Search for $H^{\pm} \longrightarrow \tau^{\pm}\nu$

JHEP 03 (2015) 088 - 19.5 fb^{-1} @ 8TeV

- Compatibility of data with background only or signal+background ?
  - Profile log-likelihood ratio test on $m_T(\tau_{had}+E_T^{miss})$





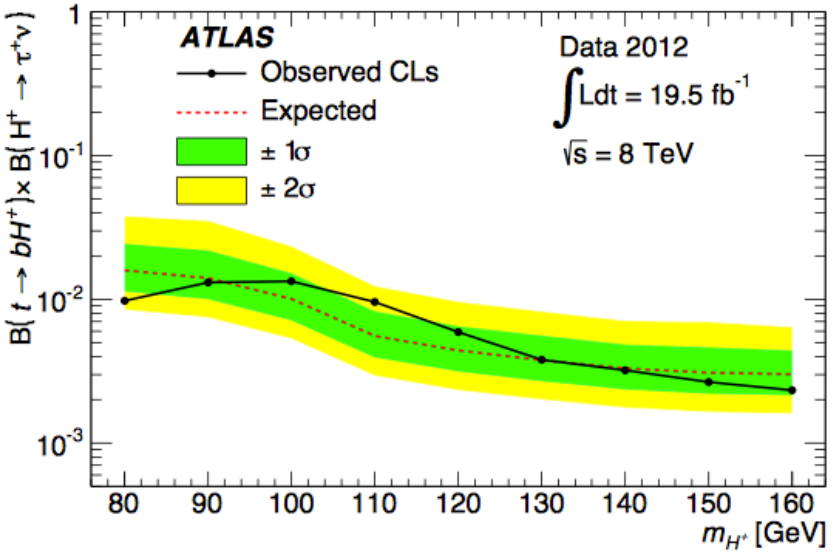
No significant deviation observed from SM predictions

Search for $H^{\pm} \longrightarrow \tau^{\pm}\nu$

JHEP 03 (2015) 088 - 19.5 fb^{-1} @ 8TeV

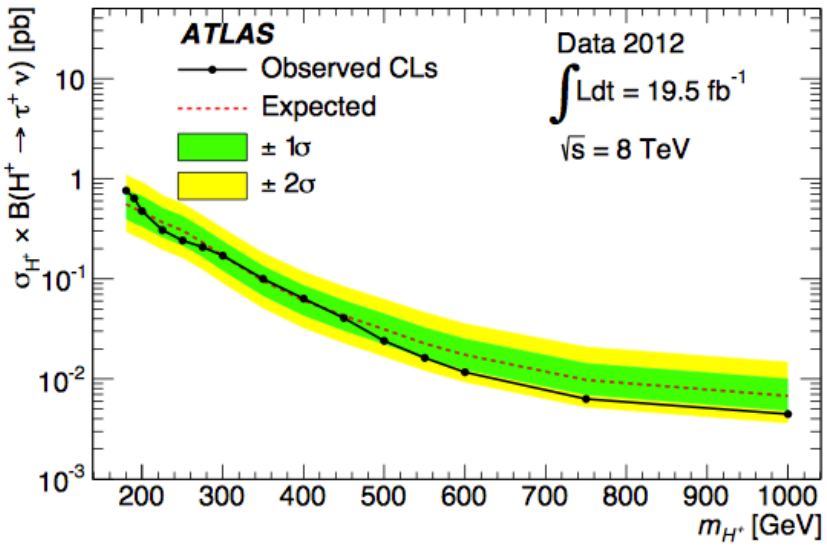
- Exclusion limits for low and high-mass regions

Results for low-mass region



Observed limits on
$B(t \longrightarrow H^{+}b) \times B(H^{+} \longrightarrow \tau^{+}\nu)$
vary between 0.23-1.3%

Results for high-mass region



Observed limits on
$\sigma(pp \longrightarrow tH^{+}+X) \times B(H^{+} \longrightarrow \tau^{+}\nu)$
vary between 0.76-3.4 fb

Search for $H^{\pm} \longrightarrow \tau^{\pm}\nu$

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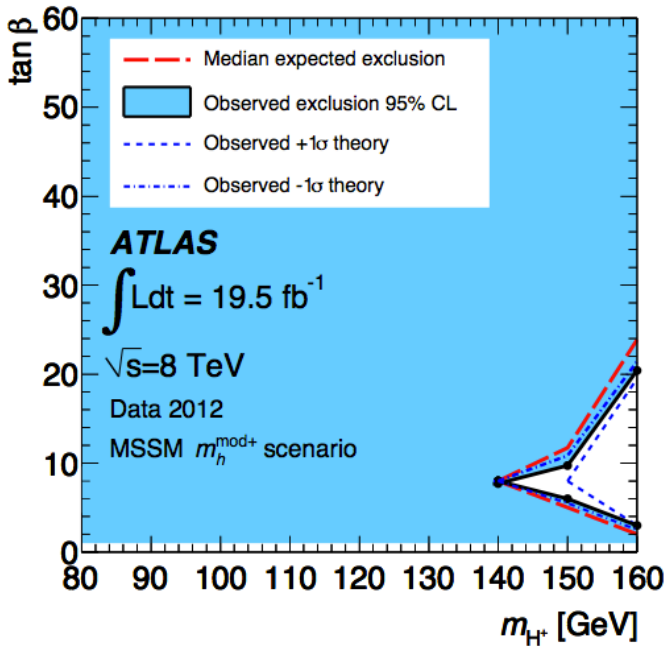
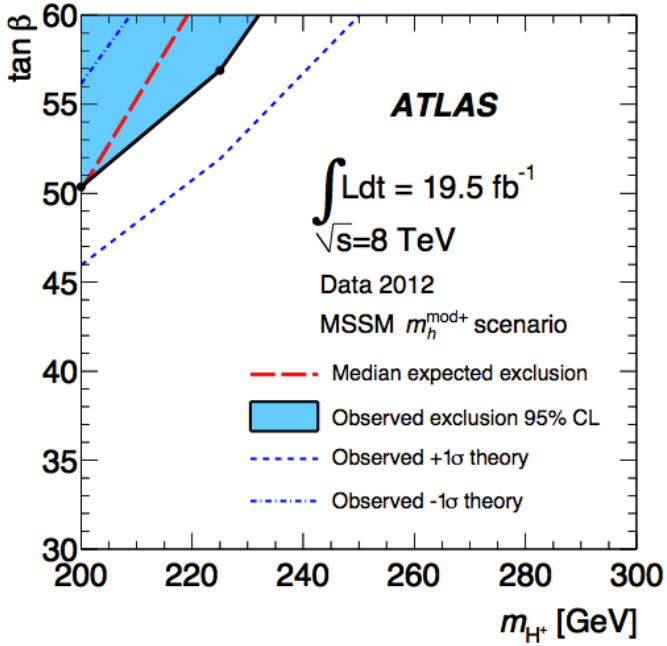
- Reinterpretation and constraints on MSSM scenarios :
  - Results for MSSM m_h^{mod+} scenario :



Entire parameter space with $\tan\beta > 1$ excluded for $m_{H^+} \in [90,140]$ GeV

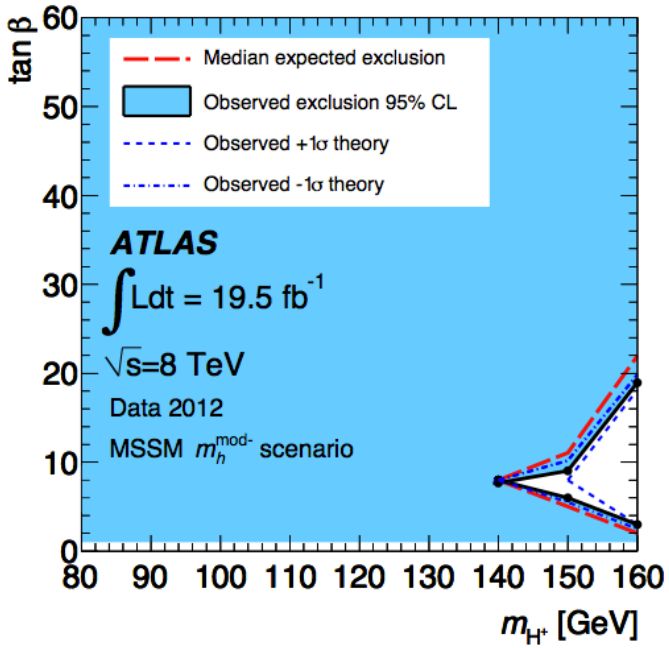


Region of parameter space with high $\tan\beta$ values excluded for $m_{H^+} \in [200,230]$ GeV

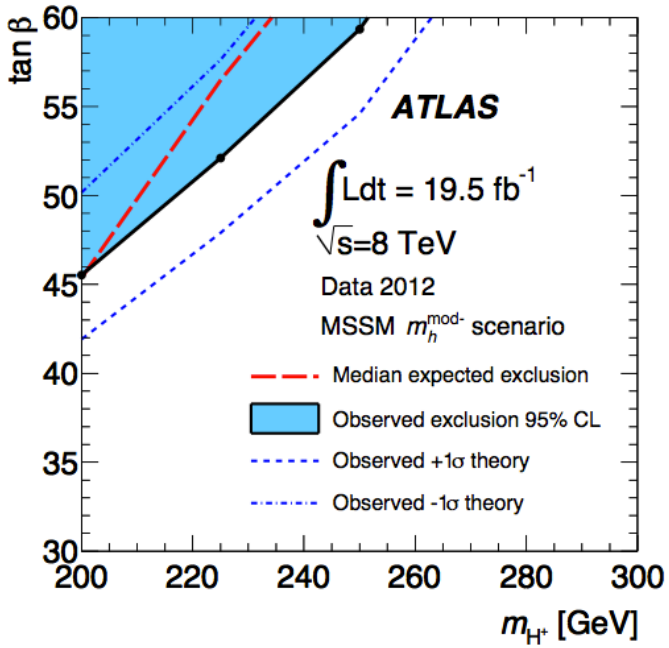
Search for $H^{\pm} \longrightarrow \tau^{\pm}\nu$

JHEP 03 (2015) 088 - 19.5 fb^{-1} @ 8TeV

- Reinterpretation and constraints on MSSM scenarios :
  - Results for MSSM m_h^{mod-} scenario :



Entire parameter space with $\tan\beta > 1$ excluded for $m_{H^+} \in [90,140]$ GeV



Region of parameter space with high $\tan\beta$ values excluded for $m_{H^+} \in [200,250]$ GeV

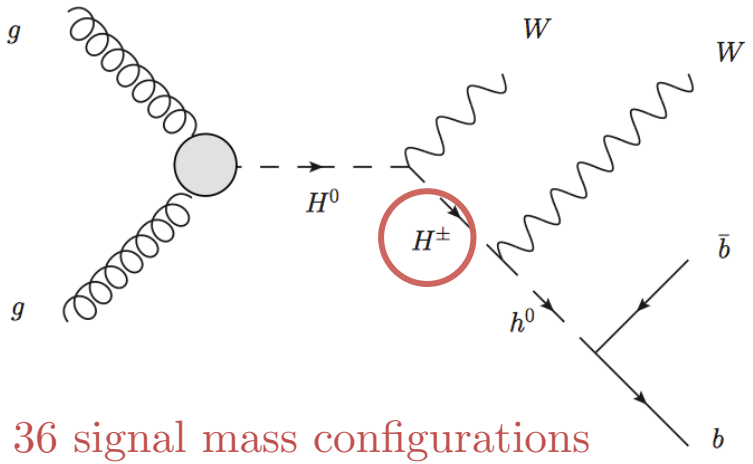
Search for Multi-Higgs boson cascade

Phys. Rev. D 89, 032002 (2014) - 19.5 fb^{-1} @ 8TeV

Multi-Higgs boson cascade

Phys. Rev. D 89, 032002 (2014) - 19.5 fb^{-1} @ 8TeV

- Search for a multi-Higgs boson cascade topology
  - Assuming other Higgs bosons ($m_{h^0} = 125$ GeV) and no particular model
  - $(W \longrightarrow l\nu)(W \longrightarrow q\bar{q}')b\bar{b}$ final states

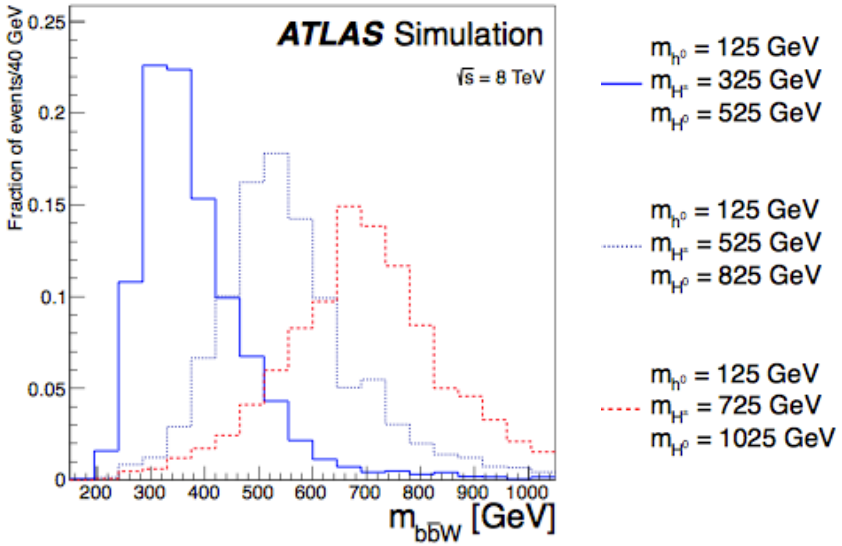


36 signal mass configurations

- $m_{H^0} \in [325\ ;\ 1025]$ GeV
- $m_{H^+} \in [225\ ;\ 925]$ GeV
- $m_{h^0} = 125$ GeV

Signature

- At least 4 jets
  - 2 b-tagged jets (70% flavour tagging eff.)
- One isolated lepton ($e^\pm$ or $\mu^\pm$) and E_T^{miss}



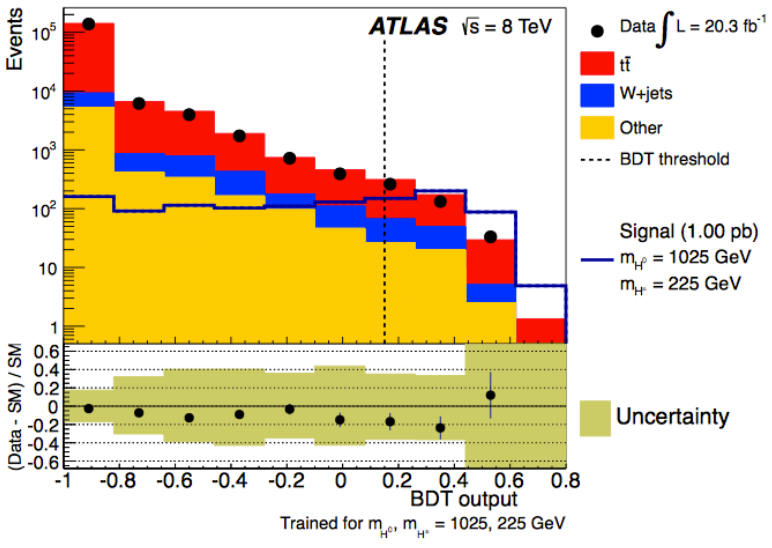
- Reconstruction of the full cascade
  - H^0 formed as $WWb\bar{b}$

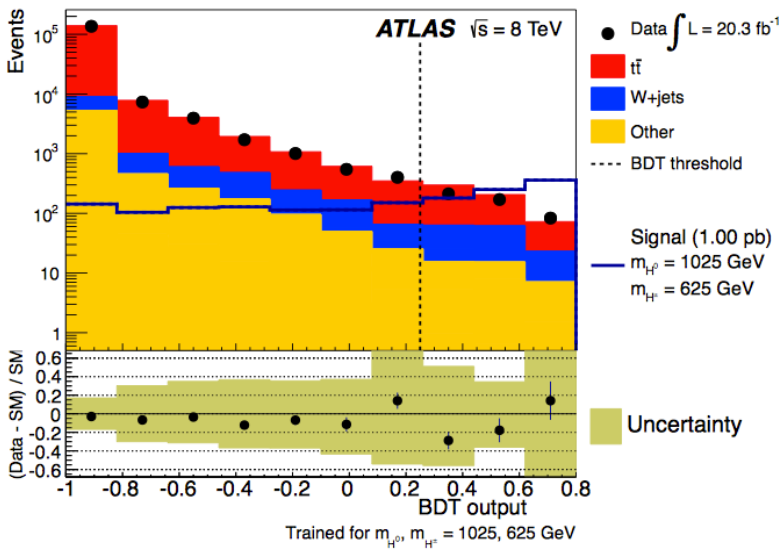
Multi-Higgs boson cascade

Phys. Rev. D 89, 032002 (2014) - 19.5 fb^{-1} @ 8TeV

- Multivariate analysis using boosted decision trees (BDT)
  - Specific BDTs trained for each signal mass configuration
  - Make use of cascade reconstruction to build discriminative variables

Two examples :



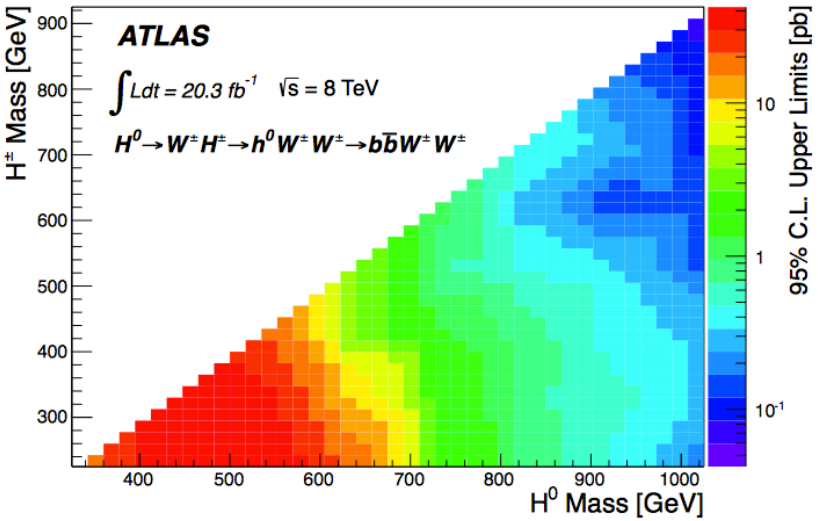


Observed yields consistent with SM background expectation

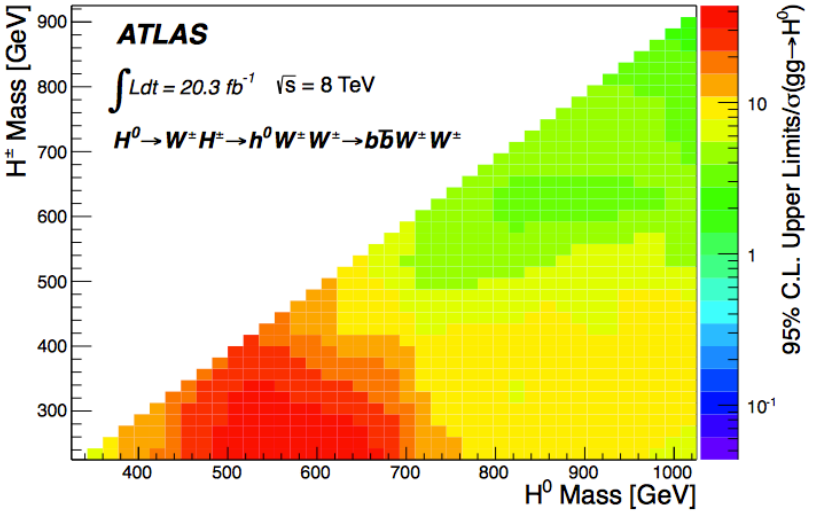
Multi-Higgs boson cascade

Phys. Rev. D 89, 032002 (2014) - 19.5 fb^{-1} @ 8TeV

- Exclusion limits on production cross section as function of m_{H^0} and m_{H^+}



Better exclusion limits obtained for high-mass region



Observed limits greater than NNLO theoretical prediction for all mass points

NB : Analysis, later reinterpreted in a 2HDM type II context, leads to same conclusions

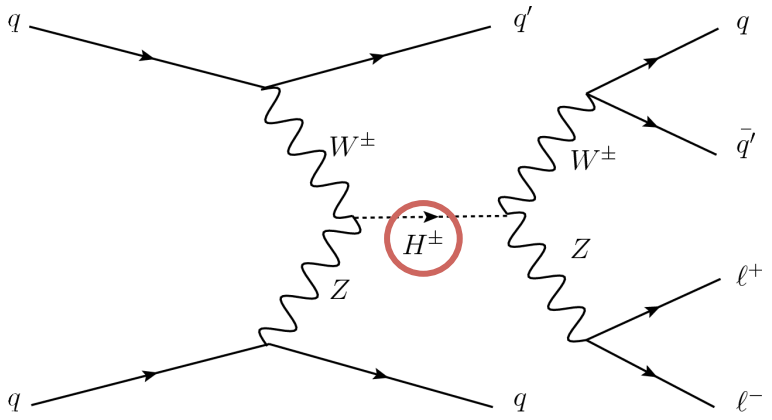
Search for $H^{\pm} \longrightarrow W^{\pm}Z$ in Vector Boson Fusion

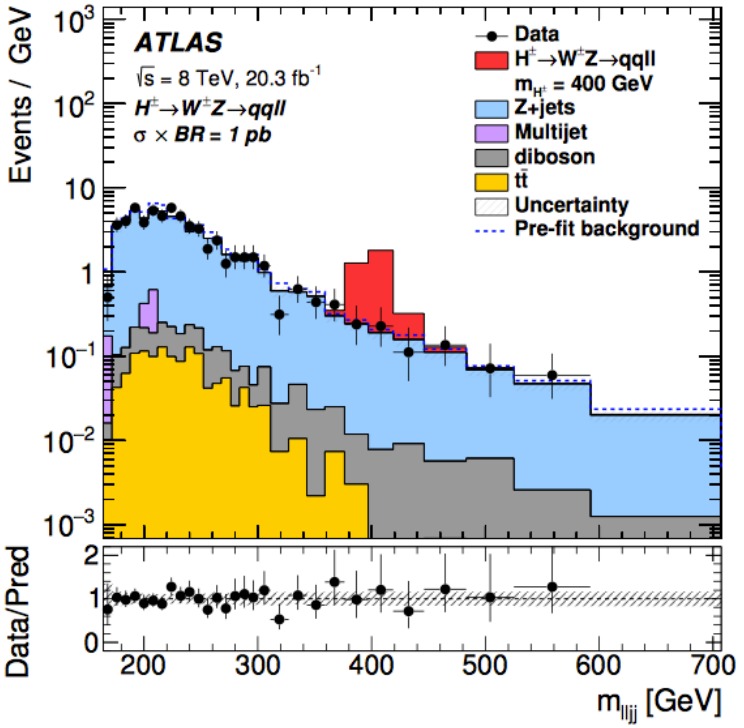
Phys. Rev. Lett. 114, 231801 (2015) - 19.5 fb^{-1} @ 8 TeV

Search for $H^{\pm} \longrightarrow W^{\pm}Z$ in VBF

Phys. Rev. D 89, 032002 (2014) - 19.5 fb^{-1} @ 8TeV

- $H^{\pm} \longrightarrow W^{\pm}Z$ allowed at tree level in Higgs Triplet Models
  - Search for $(Z \longrightarrow l^{+}l^{-})(W \longrightarrow q\bar{q}')q\bar{q}'$ final states and $m_{H^{\pm}} \in [200,1000]$ GeV





Signature

- At least 4 jets
  - Two non b-tagged jets in opposite hemispheres
  - Two highest p_T remaining central jets for $W \longrightarrow qq'$
- Exactly two isolated leptons ($e^{\pm}$ or $\mu^{\pm}$)
  - With $83 < m_{ll} < 99$ GeV

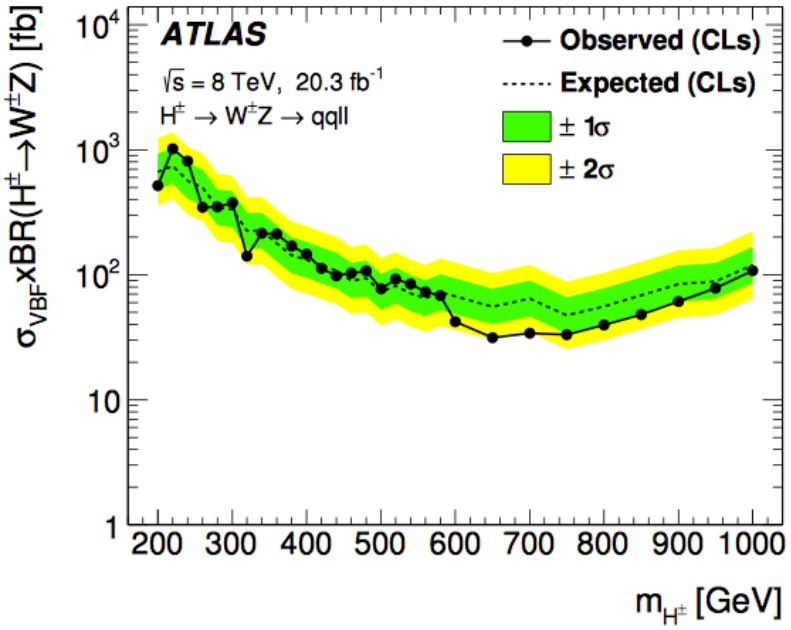
NB : Signal acceptance × efficiency = 5%, 9%, 2% respectively for $m_{H^{\pm}} = 0.2, 0.6, 1.0$ TeV

No significant deviation observed from SM predictions

Search for $H^{\pm} \longrightarrow W^{\pm}Z$ in VBF

Phys. Rev. D 89, 032002 (2014) - 19.5 fb^{-1} @ 8TeV

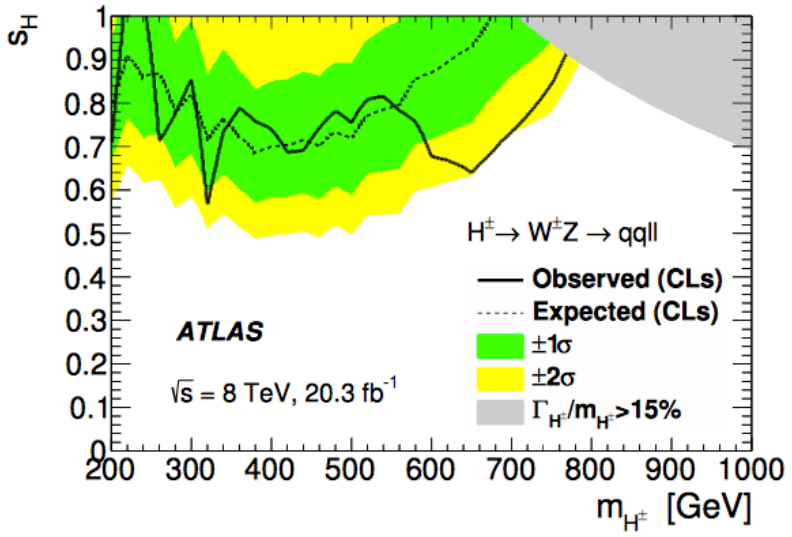
- Exclusion limits and reinterpretation in Higgs Triplet Model



Observed limits on $\sigma_{VBF} \times B(H^{\pm} \longrightarrow W^{\pm}Z)$ vary between 31-1020 *fb*

NB : Limits ×6 better than inclusive ATLAS WZ search for $m_{H^{\pm}} < 800$ *GeV*

Reinterpretation in Georgi-Machacek Higgs Triplet Model



Data exclude $m_{H^{\pm}} \in [240,700]$ GeV for $s_H = 1$ and $B(H^{\pm} \longrightarrow W^{\pm}Z) = 1$

NB : $s_H^2 = m_W^2/m_Z^2$ generated by triplet vev *(proportional to cross section and* $H^{\pm}$ *width)*

Conclusions & Outlooks

Conclusions & Outlook

- Several analyses performed at LHC Run I by ATLAS
  - In the context of MSSM
  - Investigating $H^{\pm} \longrightarrow \tau^{\pm}\nu$ channel or multi-Higgs boson cascades

(*) Stringent constrains obtained for low-mass region ($m_{H^+} < m_{top}$)

$\longrightarrow$ Excluding almost all parameter space for $\tan\beta > 1$

(*) New 8 TeV analyses able to probe higher-mass region

$\longrightarrow$ Search for $H^{\pm} \longrightarrow \tau^{\pm}\nu$: constraints above $m_{H^+} > 200$ GeV for high $\tan\beta$

$\longrightarrow$ Search for Multi-Higgs boson cascade : sensitive to the whole model

  - Investigating other theoretical interpretations and decay channels

(*) New approach searching for $H^{\pm} \longrightarrow W^{\pm}Z$ in *VBF*

$\longrightarrow$ Excluding $m_{H^+} \in [240,700]$ GeV for $s_H = 1$ and $B(H^{\pm} \longrightarrow W^{\pm}Z) = 1$

- Effort must be continued at LHC Run II : Stay tuned !

Thank you.

Back-up slides

Search for $H^{\pm} \longrightarrow \tau^{\pm}\nu$

with alternative approach

JHEP 03 (2013) 076 - 4.8 fb^{-1} @ 7TeV

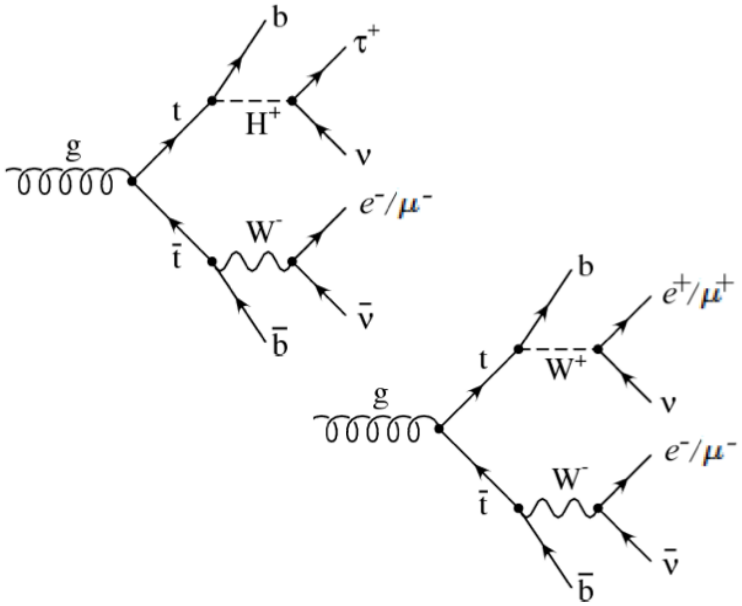
Search for $H^{\pm} \longrightarrow \tau^{\pm} \nu$ in alternative approach

JHEP 03 (2013) 076 - 4.8 fb^{-1} @ 7TeV

- Investigate lepton universality in top-quark decays
  - Measure event yields ratio R_l between two tt final states
  - Allows for cancellation of most systematics uncertainties

$$R_l = \frac{\mathcal{B}(t\bar{t} \to b\bar{b} + l\tau_{\text{had}} + N\nu)}{\mathcal{B}(t\bar{t} \to b\bar{b} + ll' + N\nu)}$$

" Excess of tt events with at least one τ in final state compared to ones with only $e^{\pm}$ or $\mu^{\pm}$ is the signature for $H^{\pm}$ boson "



Signature

- At least 2 jets
  - 2 b-tagged jets (70% flavour tagging eff.)
- Exactly one trigger matched $e^{\pm}/\mu^{\pm}$
- Either one τ jet with no add. *l'*
- Or exactly one add. *l'*
  - With different flavour than trigger-matched lepton
- E_t^{miss}

Search for $H^{\pm} \longrightarrow \tau^{\pm} \nu$ in alternative approach

JHEP 03 (2013) 076 - 4.8 fb^{-1} @ 7TeV

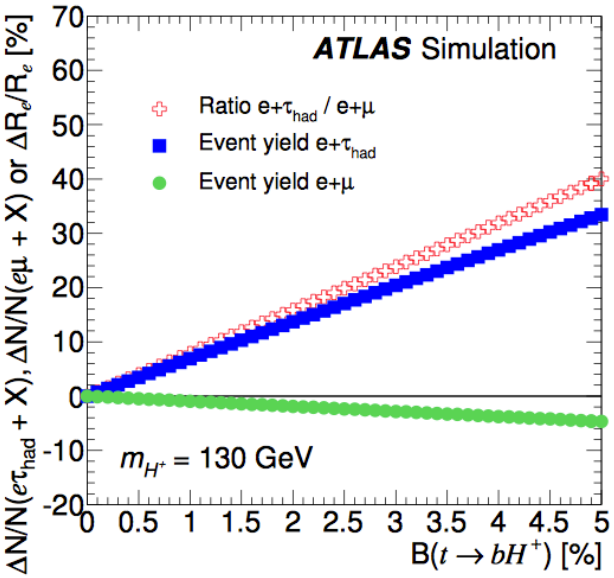
- Computation of event yield ratios
  - Re and $R\mu$ as discriminant variables

$$R_e = \frac{\mathcal{N}(e + \tau_{\text{had}})}{\mathcal{N}(e + \mu)} \qquad R_\mu = \frac{\mathcal{N}(\mu + \tau_{\text{had}})}{\mathcal{N}(\mu + e)}$$

  - SM predictions and measured values

Ratio	R_e	R_μ
SM value	0.105 ± 0.012	0.166 ± 0.017
Measured value	0.115 ± 0.010 (stat)	0.165 ± 0.015 (stat)

Dependence with $B(t \longrightarrow bH^{+})$

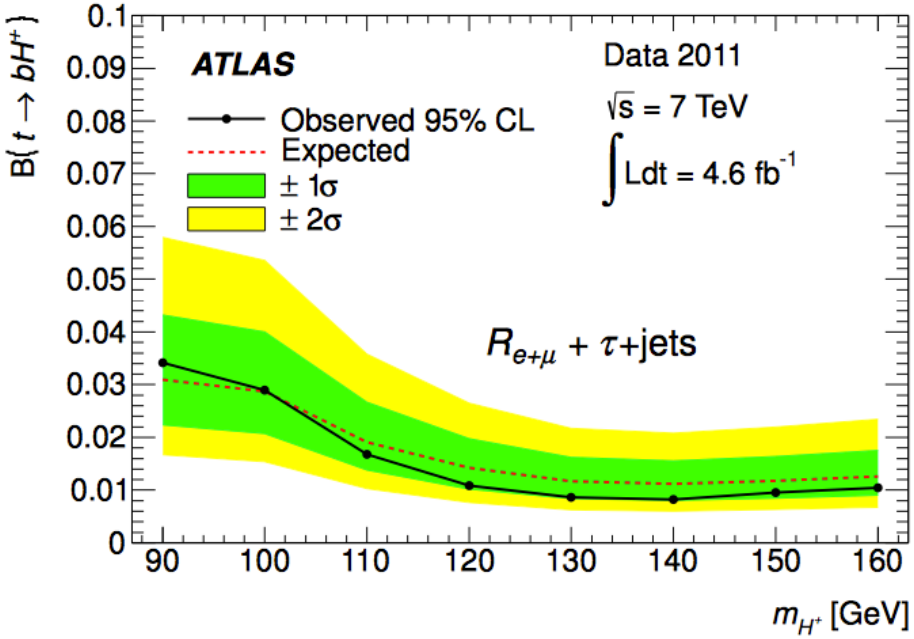


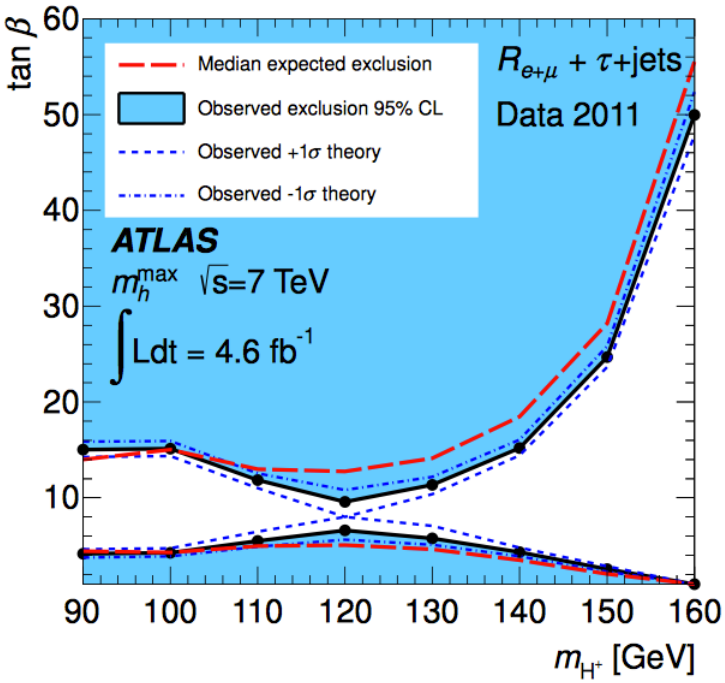
No significant deviations observed from SM prediction

Search for $H^{\pm} \longrightarrow \tau^{\pm}\nu$ in alternative approach

JHEP 03 (2013) 076 - 4.8 fb^{-1} @ 7TeV

- Exclusion limits and reinterpretation in MSSM scenarios
  - Combination of $R_{e+\mu}$ and τ_{had}+jets analyses at 7 TeV





Observed Limits on $B(t \longrightarrow bH^{+})$ vary between 3.2-4.4%

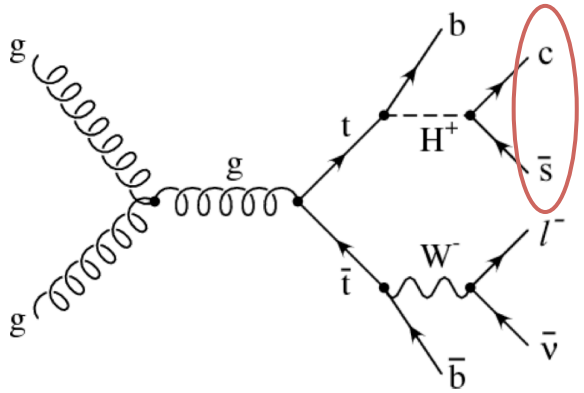
Search for $H^+ \longrightarrow c\bar{s}$

Eur. Phys. J. C, 73 6 (2013) 2465 - 4.8 fb^{-1} @ 7TeV

Search for $H^+ \longrightarrow c\bar{s}$ in $t\bar{t}$ events

Eur. Phys. J. C, 73 6 (2013) 2465 - 4.8 fb^{-1} @ 7TeV

- For light H^+ bosons ($m_{H+} < m_{top}$) $\longrightarrow$ dominant decay for tan $\beta < 1$
  - H^+ search via $t \longrightarrow H^+ b$ prod. assuming $B(H^+ \longrightarrow cs)=1$ for $m_{H^+} \in [90,150]$ GeV

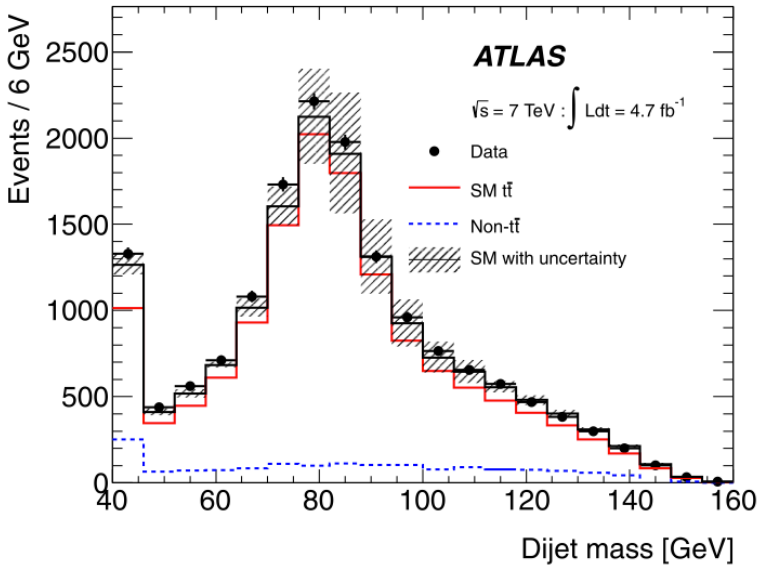


Signature

- At least 4 jets
  - 2 b-tagged jets (70% flavour tagging eff.)
- One isolated lepton : $e^{\pm}$ or $\mu^{\pm}$ and E_t^{miss}

- Search for add. bump in dijets mass dist.
  - Use kinematic fit to reconstruct dijets mass

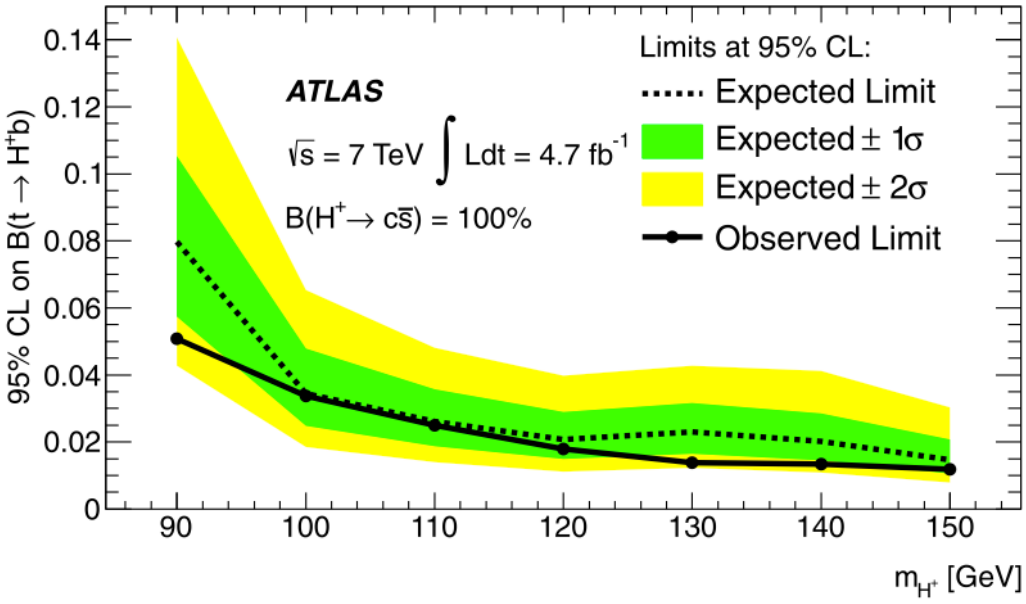
Data in good agreement with dijets mass distribution expected from SM processes



Search for $H^+ \longrightarrow c\bar{s}$ in $t\bar{t}$ events

Eur. Phys. J. C, 73 6 (2013) 2465 - 4.8 fb^{-1} @ 7TeV

- Exclusion limits for low-mass H^+ region



Observed Limits on $B(t \longrightarrow H^+ b)$ vary between 1-5%