# Charged Higgs Boson Searches at ATLAS/LHC

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**(on behalf of the ATLAS collaboration)**

**Journee de l'Irfu sur la physique du Higgs**
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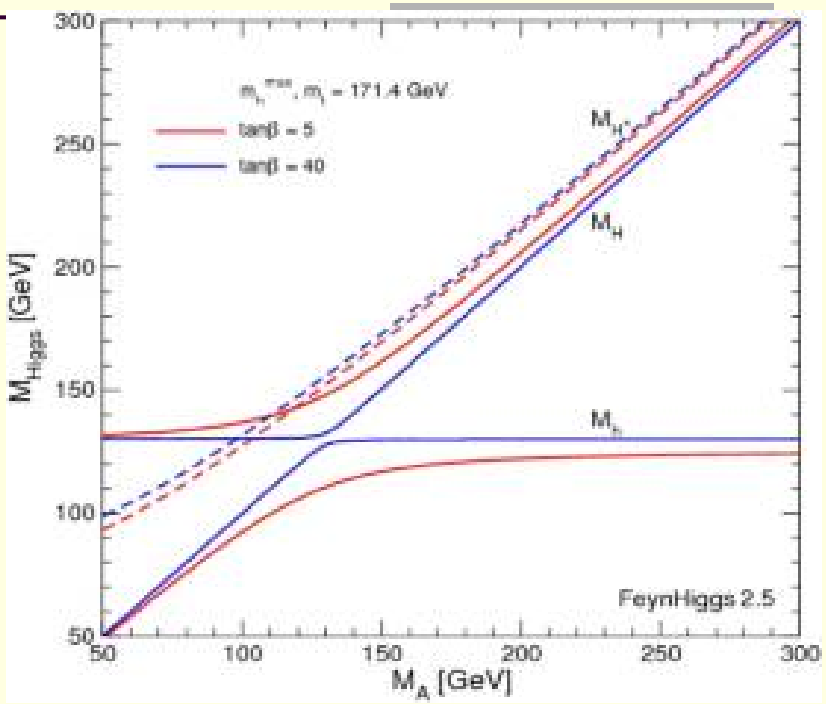
# Outline

- Introduction
  - Higgs sector of MSSM/2HDM
  - Charged Higgs production and decay
- ATLAS light Charge Higgs search channels
  - Light charged Higgs with tanβ<1: $H^{\pm} \rightarrow c\bar{s}$
    - $t\bar{t} \rightarrow bW^{\pm}(\rightarrow l\nu_l)\ \bar{b}H^{\mp}(\rightarrow c\,\bar{s})$
  - Light charged Higgs with tanβ>3: $H^{\pm} \rightarrow \tau\nu$
    - $t\bar{t} \rightarrow bW^{\pm}(\rightarrow qq')\bar{b}H^{\mp}(\rightarrow \tau_{lep}\nu)$
    - $t\bar{t} \rightarrow bW^{\pm}(\rightarrow l\nu_l)\ \bar{b}H^{\mp}(\rightarrow \tau_{lep}\nu)$
    - $t\bar{t} \rightarrow bW^{\pm}(\rightarrow qq')\,\bar{b}H^{\mp}(\rightarrow \tau_{had}\nu)$
- **Summary & Outlook**

# Higgs Sector in MSSM

- **MSSM Higgs sector consists of two complex Higgs doublet**
  - **$H_d$ ($H_u$) couples to down (up) type fermions**
  - **5 physical Higgs bosons**
    - **Neutral Higgs -- h, H, A**
    - **Charged Higgs -- $H^{\pm}$**
  - **h is predicted to be light: $m_h < m_H$ and $m_h < m_Z$(Born level).**

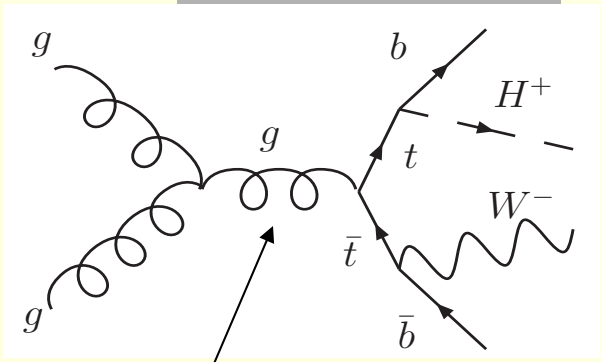


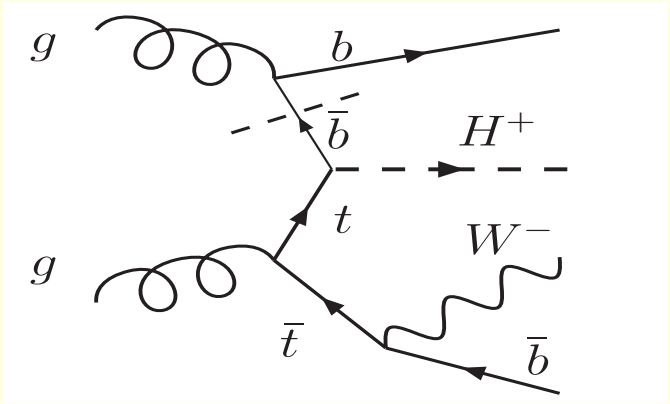

- **At tree-level, the Higgs sector is completely specified by two free parameters**
  - **$m_A$ – mass of the CP-odd neutral Higgs boson or $m_{H+}=\sqrt{(m_A^2+m_{W+}^2)}$**
  - **$\tan\beta = \langle H_u \rangle / \langle H_d \rangle$ - the ratio of the vacuum expectation values**
- **Cross sections and branching ratios are dependent on SUSY parameters through radiative corrections**

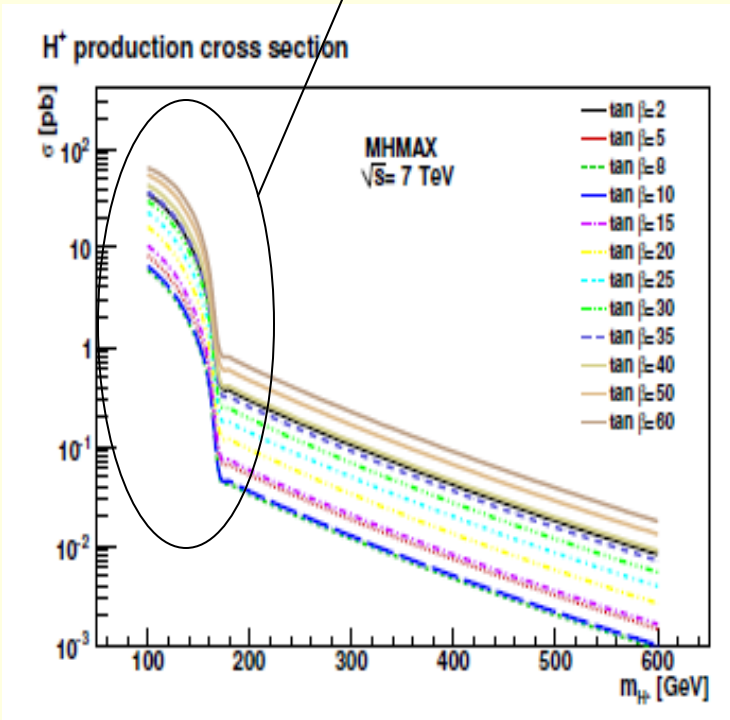
# Charged Higgs Production at LHC

- **Two different production modes depending on the mass of charged Higgs ($m_{H+}$).**
  - **Light charged Higgs ($m_{H+}<m_{top}$):**
    - **$t\bar{t} \rightarrow bW^{\pm}\bar{b}H^{\mp}$ (and $t\bar{t} \rightarrow bH^{\pm}\bar{b}H^{\mp}$)**
    - **Large production cross-section:**

      **$\sigma_{t\bar{t}}$ = 164.6 pb (NNLO)**
  - **Heavy charged Higgs ($m_{H+}>m_{top}$):**
    - **gb fusion: $gb \rightarrow \bar{t}H^{+}$**

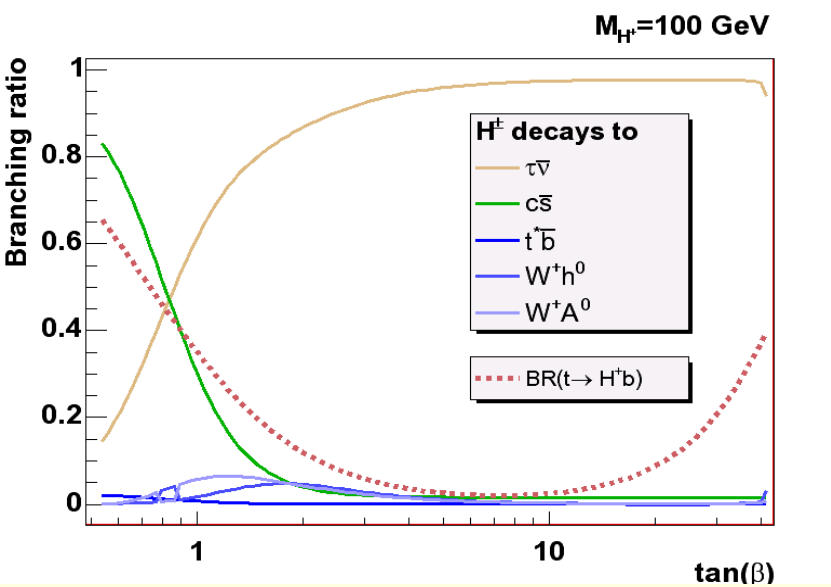


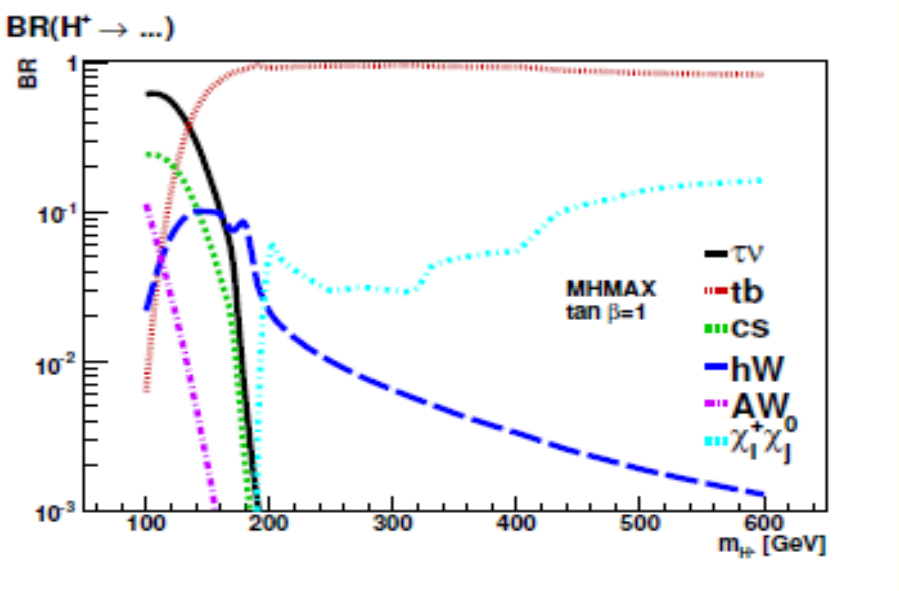



# Charged Higgs Decays

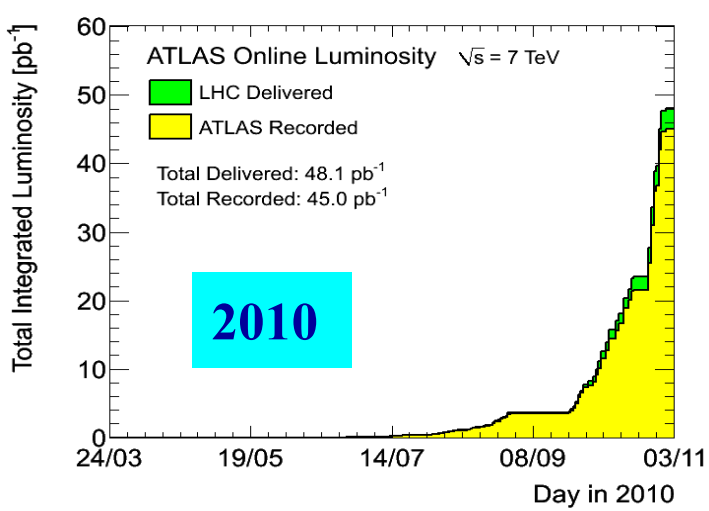
- **Decay of charged Higgs bosons are dependent on $m_{H+}$ and tanβ.**
- **If kinematically allowed, charged Higgs can decay into a pair of lightest Chargino ($\chi_1^{\pm}$)and Neutralino ($\chi^0$) or into sleptons.**
- **However, we would only consider the decays into the SM particles here. For light charged Higgs ($m_{H+}$ of 90-160 GeV), the decays are dominated $c\bar{s}$ (≈40% for tanβ<1 and $m_{H+}$ of 130 GeV)** and **$H^{\pm}\rightarrow\tau\nu$ (90% for tanβ>3 and $m_{H+}$ of 130 GeV).**

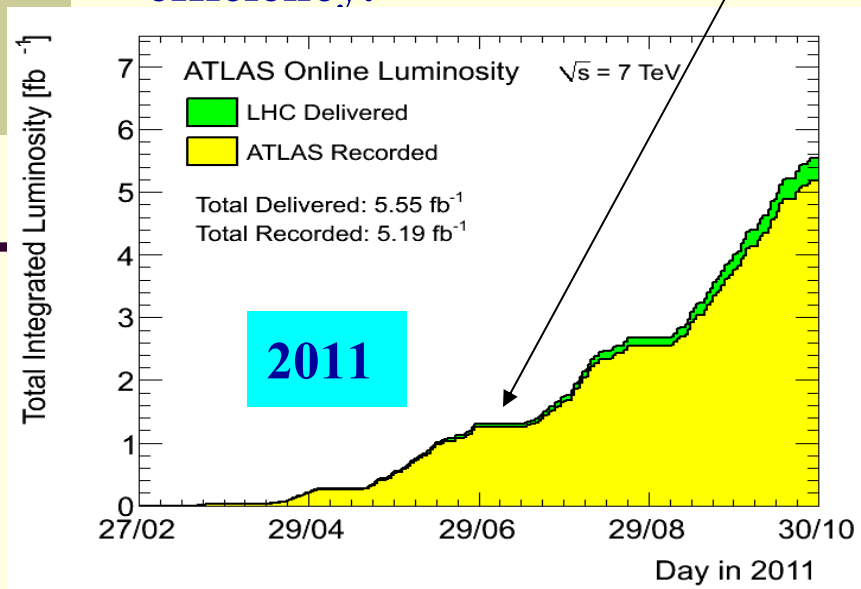


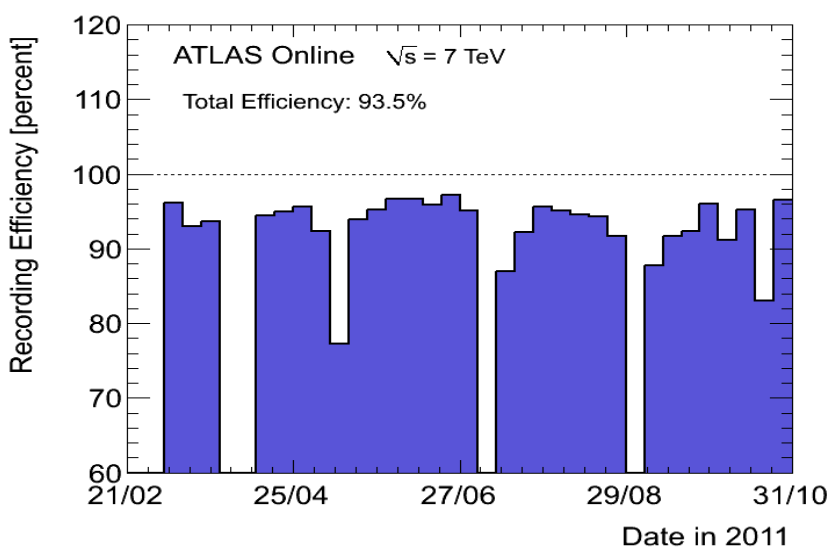



# ATLAS Dataset 2010 & 2011

- **The charged Higgs analyses presented here are with 35 pb$^{-1}$ (2010) and 1 fb$^{-1}$ (data up to the June-July 2011 technical stop).**
- **Excellent performance of the ATLAS detectors with >93% data-taking efficiency.**



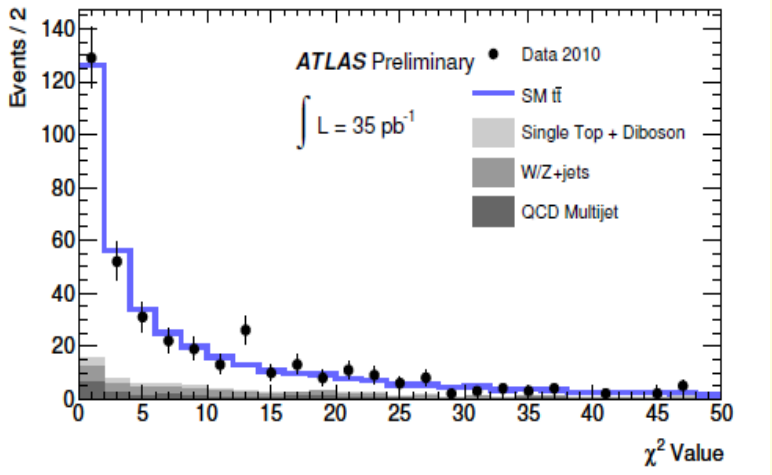



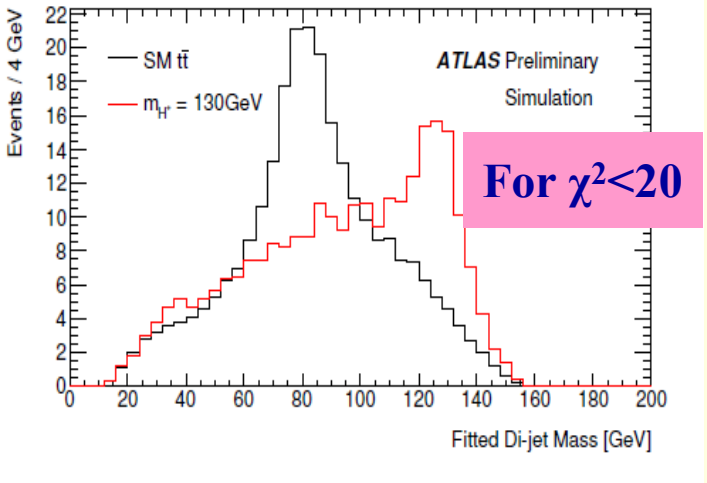



# $H^+ \rightarrow c\bar{s}$ Searches

**ATL-CONF-2011-094**

- Search for $t\bar{t} \rightarrow bW^{\pm}\bar{b}\,H^{\mp} \rightarrow bl\nu_l\bar{b}\,c\bar{s}$ signatures with one lepton, ≥4 jets (2 b-jets) and Missing $E_T$
- Event Selection
  - One e/μ with $p_T$>20 GeV
  - At least 4 jets with $E_T$>20 GeV
  - At least one b-tagged (SVX-tag) jet
  - $m_T(e,E_T^{miss})$ >25 GeV (e-channel)
  - $mT(\mu,E_T^{miss})+E_T^{miss}$>60 GeV(μ-channel)
- Full reconstruction of the $t\bar{t}$ system through kinematic fitter using W and Top mass constraints.
- 2 non b-tagged jets are assigned to the $H^+ \rightarrow c\bar{s}$ decay
- 35 $pb^{-1}$ results; 2011 data analysis in progress



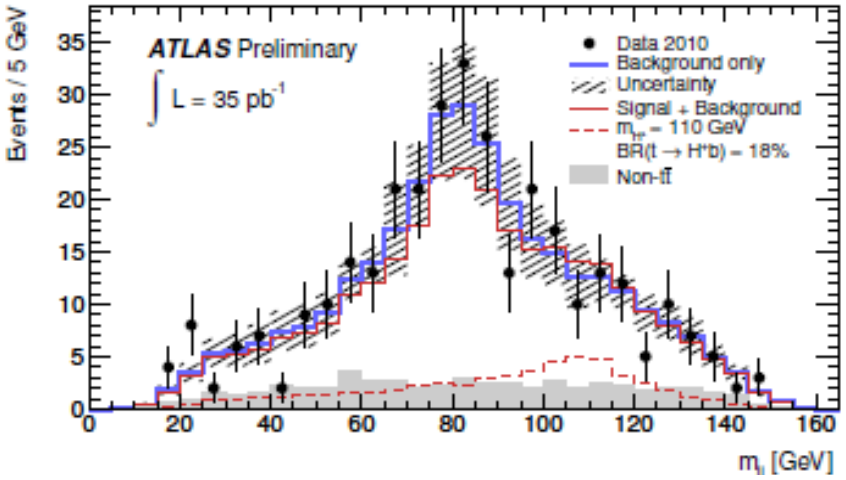



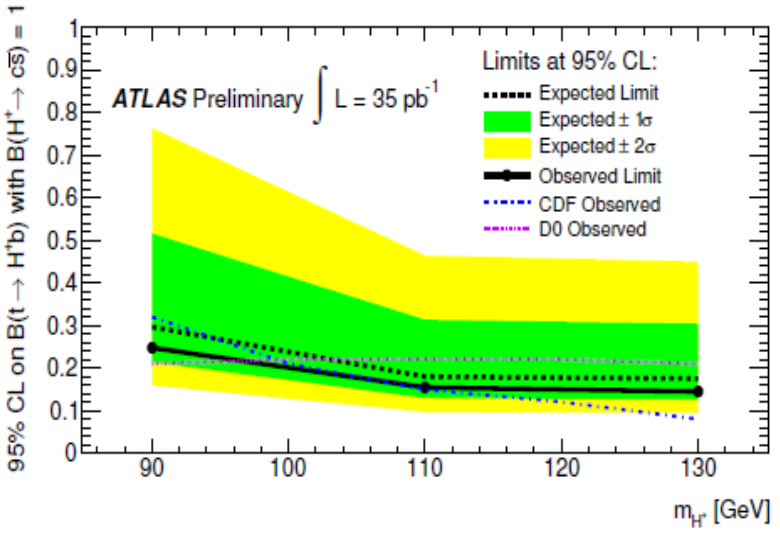

For $\chi^2$<20

# $H^+ \rightarrow c\bar{s}$ Searches

**ATL-CONF-2011-094**

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




- **Observed limits are consistent with background only hypothesis**
- **Quite competitive with the Tevatron limits**
- **JES and b-tagging are the dominant systematics**

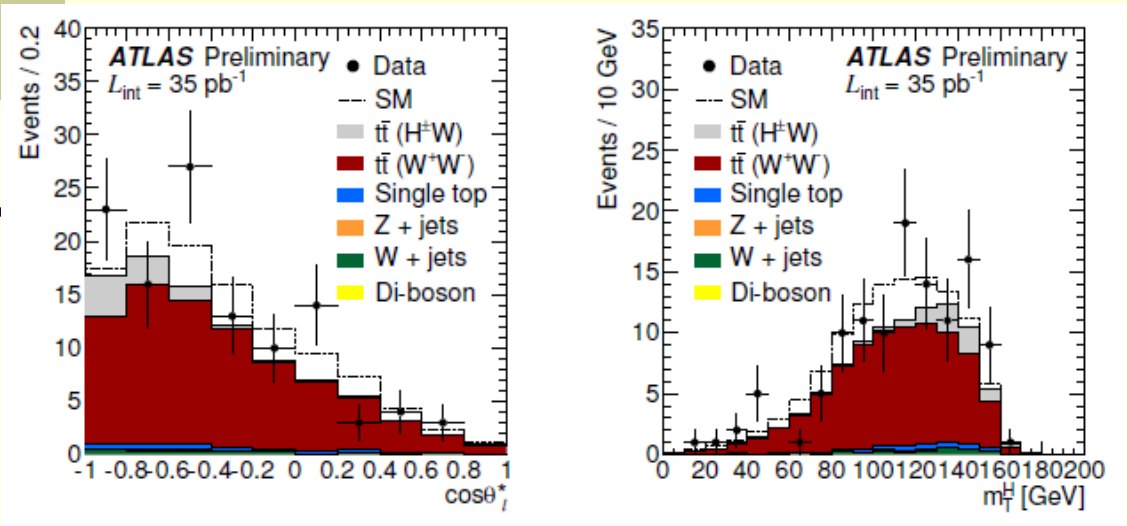
# $H^+ \rightarrow \tau_{lep}\nu$ Searches

## Study of discriminating variables

**ATL-CONF-2011-018**

$$\cos\theta_l^* = \frac{2m_{bl}^2}{m_{top}^2 - m_W^2} - 1 \simeq \frac{4\,p^b \cdot p^l}{m_{top}^2 - m_W^2} - 1 \text{ with } p^b \cdot p^l = 2E_bE_l(1-\cos\theta_{bl}) = 4E_bE_l\sin^2(\theta_{bl}/2).$$

$$(m_T^H)^2 = \left(\sqrt{m_{top}^2 + (\vec{p}_T^{\,l} + \vec{p}_T^{\,b} + \vec{p}_T^{\,miss})^2} - p_T^b\right)^2 - \left(\vec{p}_T^{\,l} + \vec{p}_T^{\,miss}\right)^2$$



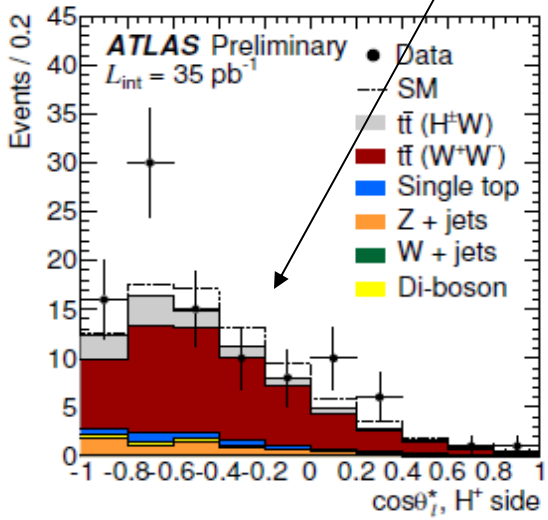

- $t\bar{t} \rightarrow bW^{\pm}\bar{b}\,H^{\mp} \rightarrow bqq'\bar{b}\,\tau_{lep}\nu_\tau$
- **Likelihood techniques for bqq' assignment**
- **Studies performed on 2010 dataset and analysis on 2011 data ongoing**

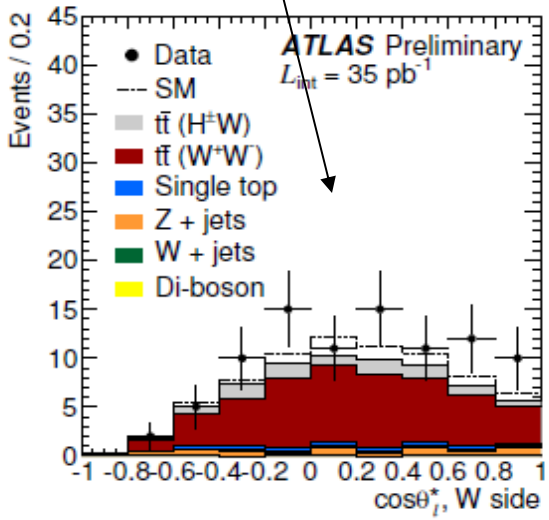
# $H^+ \rightarrow \tau_{lep}\nu$ Searches

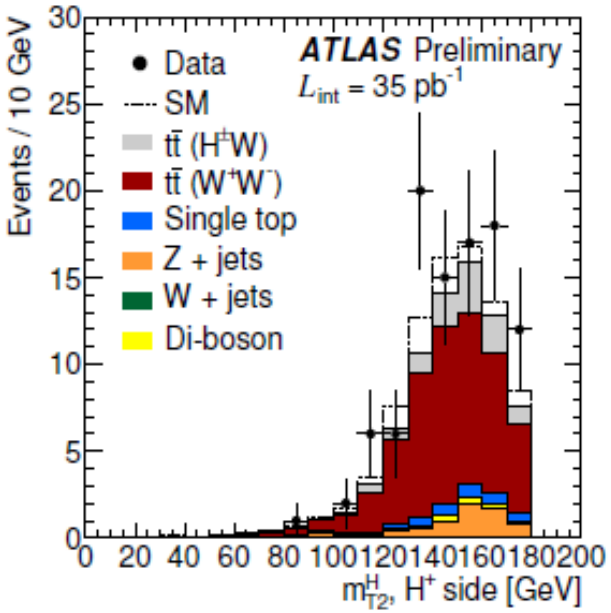
## Study of discriminating variables

ATL-CONF-2011-018

- $t\bar{t} \rightarrow bW^{\pm}\bar{b}\,H^{\mp} \rightarrow bl\nu_l\bar{b}\,\tau_{lep}\nu_\tau\,\bar{b}$
- Same variables as in the last slide
- The assignment of $\cos\theta_{H\text{-side}}$ and $\cos\theta_{W\text{-side}}$
- Studies performed on 2010 dataset and analysis on 2011 data ongoing

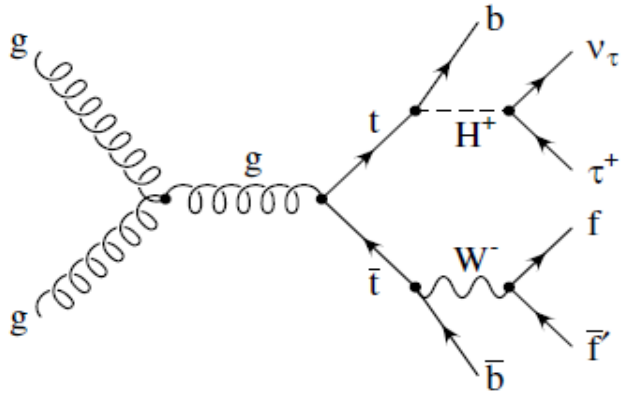


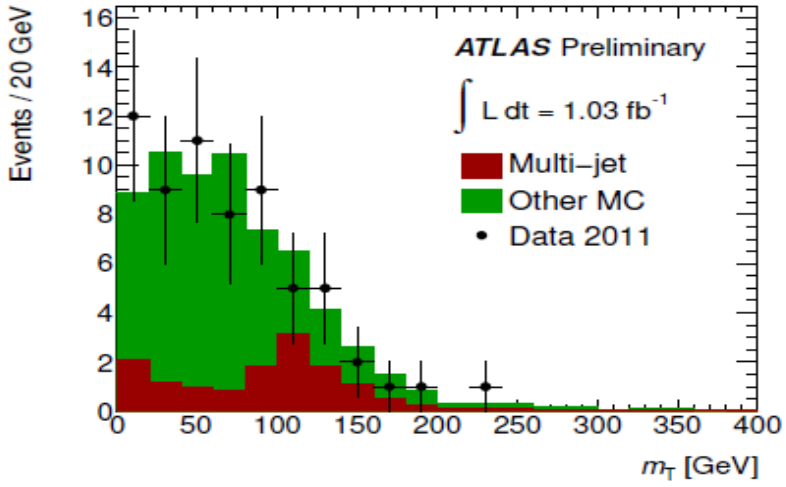
# $H^+ \rightarrow \tau_{had}\nu$ Searches

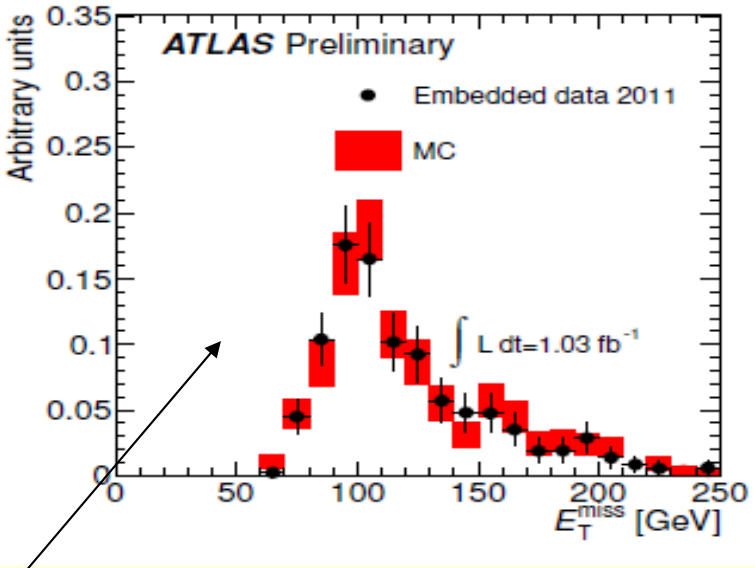
**ATL-CONF-2011-138**




- $t\bar{t} \rightarrow bW^{\pm}\bar{b}H^{\mp} \rightarrow bqq'\bar{b}\tau_{had}\nu$
- Dominant backgrounds
  - SM $t\bar{t}$, multijet QCD, single top, W+jets
  - Estimated using data-driven techniques
- Event Selection
  - Trigger: Missing $E_T$> 35 GeV and τ-lepton $E_T$>29 GeV
  - Offline object selection:
    - One τ-jet $p_T$>35 GeV and |η|<2.3 (matched with trigger object)
    - At least 4 jets with $E_T$>20 GeV and |η|<2.5; event vetoing with e(μ) having $E_T$>20 ($p_T$>10) GeV
    - Missing $E_T$>40 GeV and at least one b-tagged jet.
    - Highest $p_T$ combination for qq'b in the range of 120-240 GeV
- Transverse mass reconstruction: $\sqrt{[2p_T^{\tau} E_T^{miss}(1-\cos\Delta\varphi)]}$

# $H^+ \rightarrow \tau_{had}\nu$ Searches



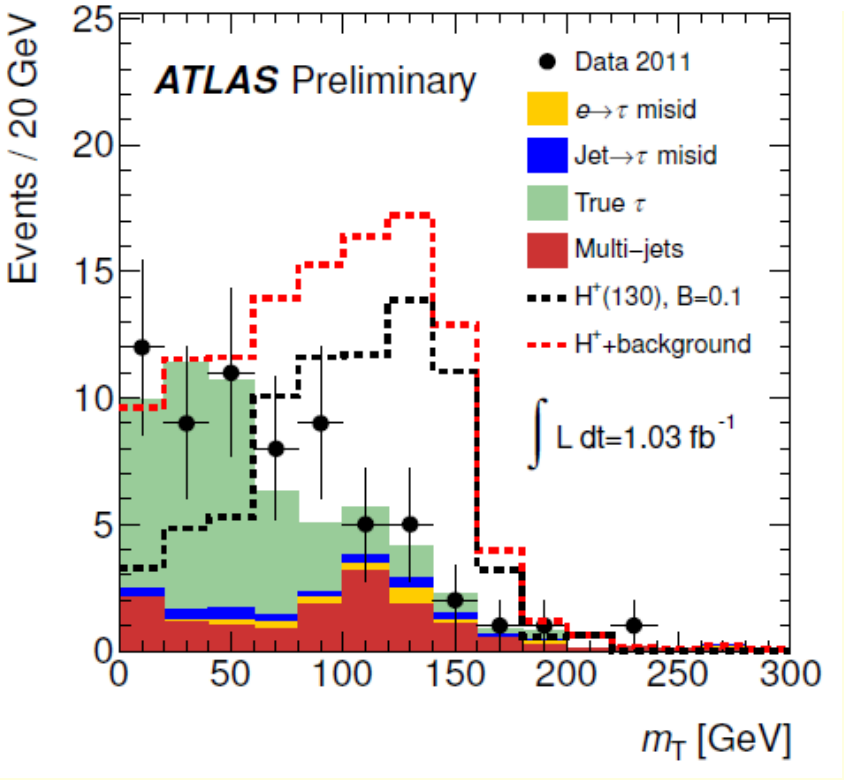

- **Data-driven background estimation**
  - **Probabilities for electron and jet to fake the τ-jet signature (estimated in $Z \rightarrow e^+e^-$ and γ+jet data)**
    - **Applied on SM $t\bar{t}$, single top and W+jets MC**
  - **Contribution from Multijet QCD estimated directly from data**
  - **Contributions from true τ-jets are estimated using embedding techniques and validated on SM $t\bar{t}$ processes.**
    - **Selecting a sample from data with muons**
    - **Replacing the muon with a τ-jet and re-reconstruct the event**

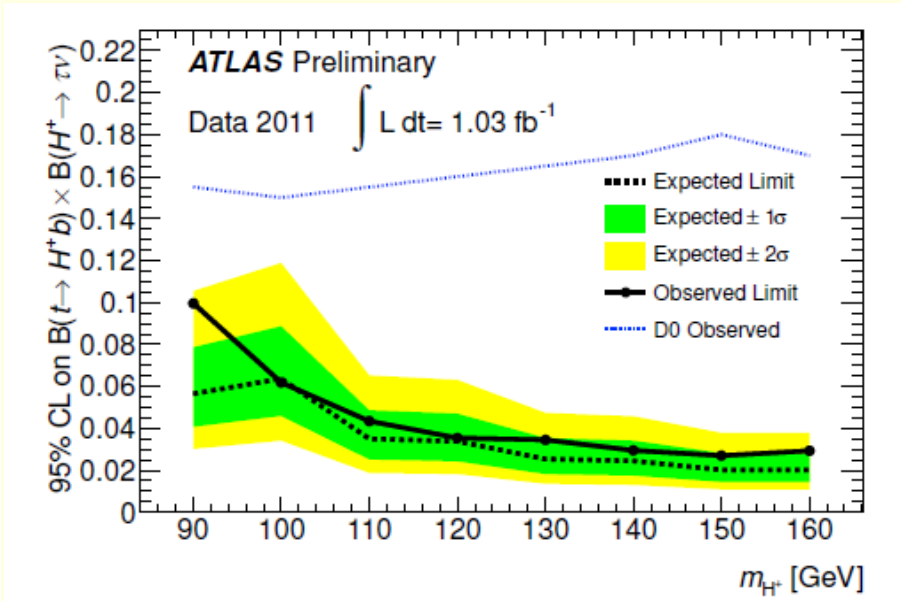
**ATL-CONF-2011-138**

# $H^+ \rightarrow \tau_{had}\nu$ Searches

**ATL-CONF-2011-138**

| | Events with/from | | | | | |
|---|---|---|---|---|---|---|
| | true $\tau$ jets | jet $\rightarrow \tau$ mis-id | $e \rightarrow \tau$ mis-id | multi-jet | expected (sum) | data |
| $m_T > 40$ GeV | $21 \pm 5$ | $2.4 \pm 0.7$ | $1.9 \pm 0.2$ | $12 \pm 5$ | $37 \pm 7$ | 43 |




**$Br(t \rightarrow H^+b) \times Br(H^+ \rightarrow \tau_{had}\nu)$ <3-10% @95% CL for $m_{H^+} \approx$ 90-160 GeV**

# Summary & Outlook

- **Several search channels for light charged Higgs bosons have been explored by ATLAS with $35^{-1}$ of 2010 data and no significant excess have been found over the SM background processes.**
- **ATLAS exclusion limits on $Br(t\rightarrow H^{+}b)*Br(H^{+}\rightarrow\tau\upsilon)$ based on 1 $fb^{-1}$ dataset considering single search channel provide extremely good sensitivity over the charged Higgs mass range of 90-160 GeV.**
- **Searches on $H^{+}\rightarrow\tau_{lep}\upsilon$ channels using the discriminating variables on larger dataset are ongoing and expected to improve the sensitivity further.**
- **With $35^{-1}$ dataset ATLAS $H^{+}\rightarrow c\bar{s}$ results are already competitive with the Tevatron ones.**
- **5.2 $fb^{-1}$ dataset have already been recorded; ATLAS is likely to exclude a significant region of $Br(t\rightarrow H^{+}b)$ vs $m_{H+}$ space or discover charged Higgs.**
- **Search for heavy charged Higgs bosons ($m_{H+}>m_{top}$) are also being pursued.**