Systematics in charged Higgs searches in ATLAS

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on behalf of ATLAS Collaboration

Outline

- **Light H^+ search & expected upper limits for Br(t → H^+ b) :**
- **$\sqrt{s}$=10 TeV , L_{int} =200 pb^{-1}, $\sqrt{s}$=7 TeV , L_{int} = 1 fb^{-1}** (rescaling)

H^+ → c sbar **H^+ → $\tau^+_{lep}\,\nu$**

(see talk Un-ki Yang & Miika Klemetti & Arnaud Ferrari)

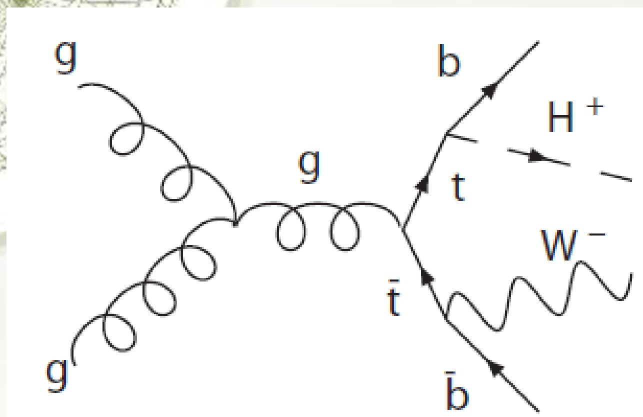
- **Impact of systematics uncertainties**
- **Conclusions**
- The material presented here is based on ATLAS notes

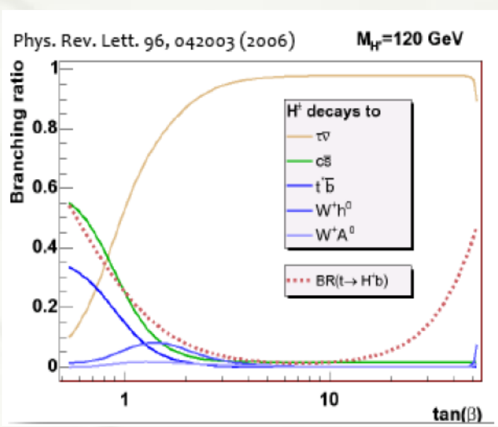
  ATL-PUB-2010-006 and ATL-PUB-2010-009

Previous studies at **$\sqrt{s}$=14 TeV at L_{int} = 10 and L_{int} = 30 fb^{-1}** on **light** and **heavy charged Higgs** are: Expected Performance of ATLAS Experiment-Detector,Trigger and Phyiscs , arXiv:0901.0512[hep-ex]

The systematics discussion is deeply linked to analysis and the key point of analysis procedure have to be reminded.

Light charged searches at LHC





- **Light H^+ ($m_{H+} < m_{top}$)** are produced primarly through top decay**: t → H^+ b** (and c. c.)
- Search for tt bar event with one the tops decaying in **H^+ instead W^+**, while the other decays to **W^-, with subsequent leptonic decays**
- **Main background SM top pair production**
- tan β <1 **H^+ → c sbar**
- tan β >1 **H^+ → $\tau^+_{lep}\,\nu$**

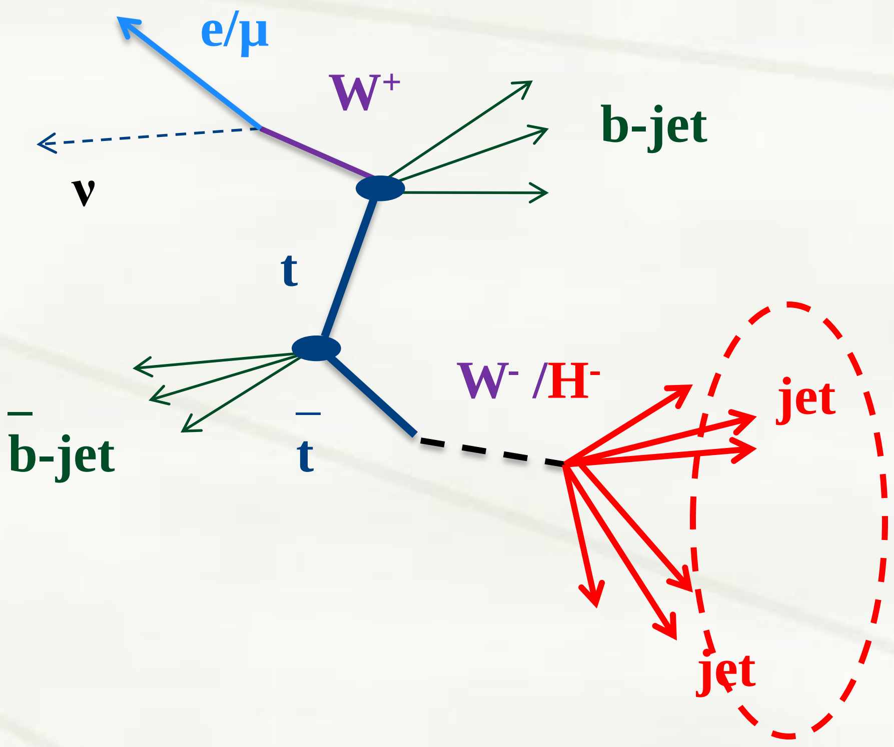
Semileptonic channel :
$H^+ \rightarrow$ c s bar

tan β < 1

- In SM Br($t \rightarrow W^+ b$)~ 1
- tbar→ $H^- bbar$ would appear as 2nd peak in di-jets mass distribution

Analysis method:(key points)

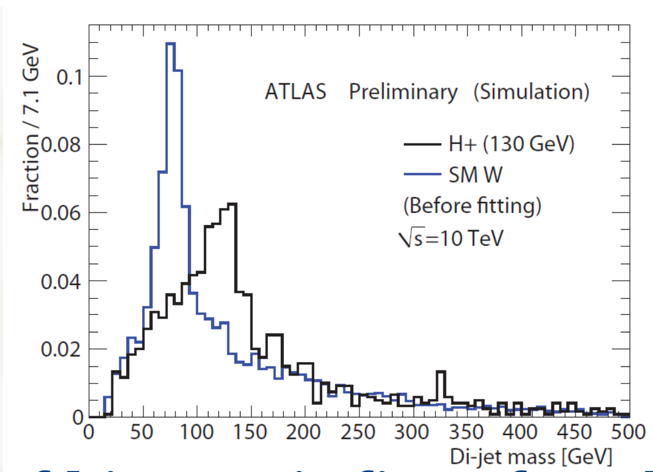
- **only one lepton(e,μ):** **p_T> 20 GeV |η| <2.5**
- **E_T^{miss} >20 GeV**
- **At least 4 jets** **p_T> 20 GeV |η| <2.5**
- **Two of 4jets b-tagged**

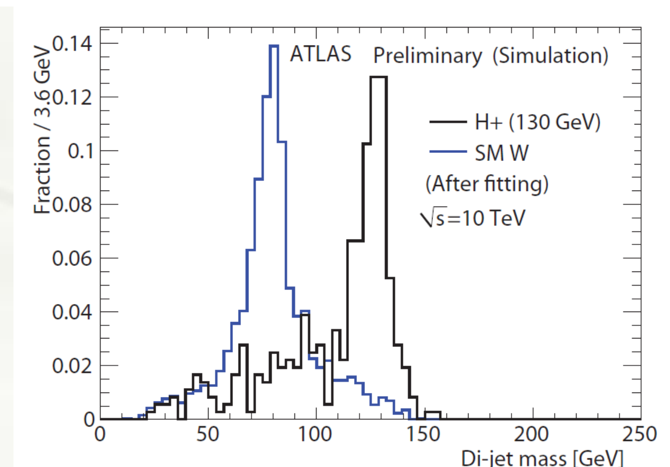


Dijet mass distribution & fitter

- The analysis is performed by considering the **shapes** of di-jet mass distribution.

$$\chi^2 = \sum_{i=l,4\text{jets}} \frac{\left(p_T^{i,\text{fit}} - p_T^{i,\text{meas}}\right)^2}{\sigma_i^2} + \sum_{j=x,y} \frac{\left(p_j^{\text{UE,fit}} - p_j^{\text{UE,meas}}\right)^2}{\sigma_{UE}^2} + \sum_{k=jjb,bl\nu} \frac{(M_k - M_{\text{top}})}{\sigma_{\text{top}}^2} + \frac{(M_{l\nu} - M_W)^2}{\sigma_W^2}$$





➤**Usage of kinematic fitter for ttbar event reconstruction provides better separation between H^+ and W^+ mass distribution**

Fitter for **$H^+ \rightarrow$ c sbar** mass reconstruction

- Reconstruction of entire ttbar event: W^+ mass constraints on leptonic W^+ decays and top mass requirement
- For each combination (4) **Jet energy scaled using predefined light jet correction accounting the measured jet energy vs η**. Additional parton level corrections specific to ttbar kinematics (derived using MC@NLO)
- Mass Fitter applied to extract the **most likely jet assignement correct and improve the resolution**
- Fitter: φ and η particle fixed. Measured momenta can vary inside resolution
- σ jet has been estimated vs pt (MC@NLO)
- Unclustered energy 0.4 √ UE (small)
- Combination with lowest χ^2 (χ^2 <10 and M_{top} < 195 GeV)
- If the best combination doesn't pass this cut event rejected.

Remarks

- This analysis is essentially **a shape comparison** and it sensitive to Jet Energy Scale (JES) which alter the shape of dijet mass distribution
- The calibration method reduces this effect using ttbar events template. This technique corrects for systematic bias caused from JES.
- Any relative bias between light and b quark is not taken in account .The calibration is derived from W mass
- In future this bias can be reduced by calibrating b-jets using top quark mass.

Sensitivity

$\mathscr{S} = N_{\rm sig}/\sqrt{N_{\rm bg}},$

H^+ mass in GeV	90	110	130	150
$\mathscr{B}(t \to bH^+)$	22%	15%	8%	13%
$\mathscr{S} = N_{\rm sig}/\sqrt{N_{\rm bg}}$	5.9	4.9	3.3	4.0

Assuming the Tevatron upper limits for $\mathscr{B}(t \to bH^+)$

- To find **an upper limit** $\mathscr{B}(t \to bH^+)$ **at 95 % CL** $\mathscr{B}(H^+ \to c\bar{s}) = 1.$

$$LH = \prod \frac{\nu_i^{n_i} \times e^{-\nu_i}}{n_i!} \bigotimes G(N_{bkg}, \sigma_{N_{bkg}}),$$

$$\nu_i = N_{t\bar{t}} \times 2\mathscr{B}(t \to H^+ b)[1 - \mathscr{B}(t \to H^+ b)] \times A_{H^+} \times P_i^{H^+} \times \mathscr{B}(W \to \ell\nu)$$
$$+ N_{t\bar{t}} \times [1 - \mathscr{B}(t \to H^+ b)]^2 \times A_W \times P_i^W \times \mathscr{B}(W \to \ell\nu)[2 - \mathscr{B}(W \to \ell\nu)] + N_{bkg} \times P_i^{bkg}.$$

- Three **fit parameters** $\mathscr{B}(t \to bH^+)$ $N_{t\bar{t}}$, N_{bkg} (constrained with δσ= 30%)

- **Obtain 95% CL upper limit on** $\mathscr{B}(t \to bH^+)$ **using 10000 pseudo experiments**

Sources of Systematics on Branching Ratio **Branching Ratio**

- **Relevant impact**

Uncertainty on:

- Jet Energy Scale(JES)
- Jet Energy Resolution(JER)
- Initial & final state radiation (ISR&FSR)
- MC generator used

- **Limited impact**

Any source which affects at same level signal and background:

- Luminosity
- σ_{ttbar}
- $\varepsilon_{trigger}$
- ε_{recon}
- b-tag (if $M_H \sim M_W$)

Effect :

- Change **selection** acceptance H and W events
- Perturb **dijet mass** distribution

Systematic Uncertainties

- Upper limit change $\mathscr{B}(t \to bH^+)$ varying **±1σ each source of systematic**
- The **same procedure** to extract Br is performed using a **new perturbed dijet mass distribution.**

Systematic	Definition $\pm 1\sigma$
Jet Energy Resolution ($\|\eta\| < 3.2$)	$0.45 * \sqrt{E}$
Jet Energy Resolution ($\|\eta\| > 3.2$)	$0.63 * \sqrt{E}$
Jet Energy Scale ($\|\eta\| < 3.2$)	$\pm 7\%$
Jet Energy Scale ($\|\eta\| > 3.2$)	$\pm 15\%$
b-jet Energy Scale	b-tagged jet energy $\pm 3\%$
Lepton Energy Scale	$\pm 1\%$

- **MC generator:** comparing MC@NLO and AcerMC.
- **Acceptance** change varying **ISR/FSR** showering in Pythia **on ttbar sample**

Jet Energy Scale

- Important effect: **acceptance variation due to JES uncertainty.**
- **JES calibration on ttbar sample.**
- The peak position of the dijet mass distribution (perturbed) compared with value of the nominal sample (Gaussian fit range 2σ) ➡ **rescaling factor**
- JES systematic sample &ISR/FSR sample are recalibrated .
- After **JES recalibration** the analysis is largely **insensitive to JES**

m_H=130GeV

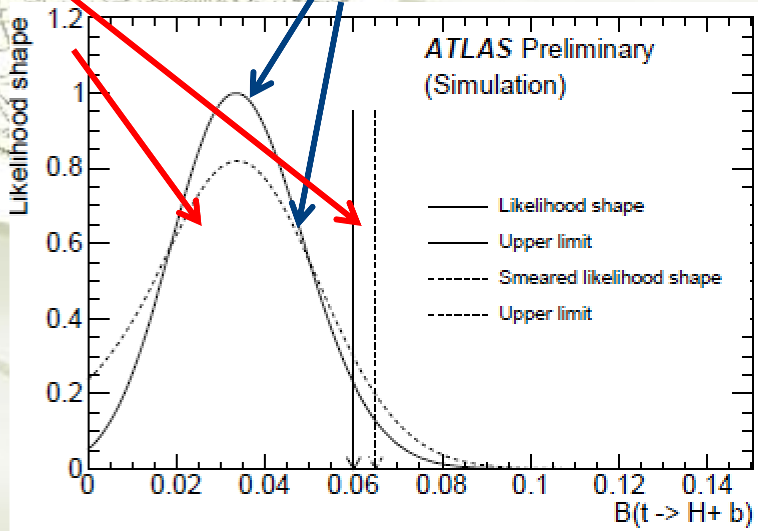
Systematic	$\Delta\mathscr{B}$
Jet Energy Resolution	0.71%
Jet Energy Scale	0.07%
MC Generator	0.56%
ISR/FSR	0.54%
b-jet Energy Scale	0.75%
Lepton Energy Scale	0.08%
Combination in quadrature	1.26%

Including Systematics

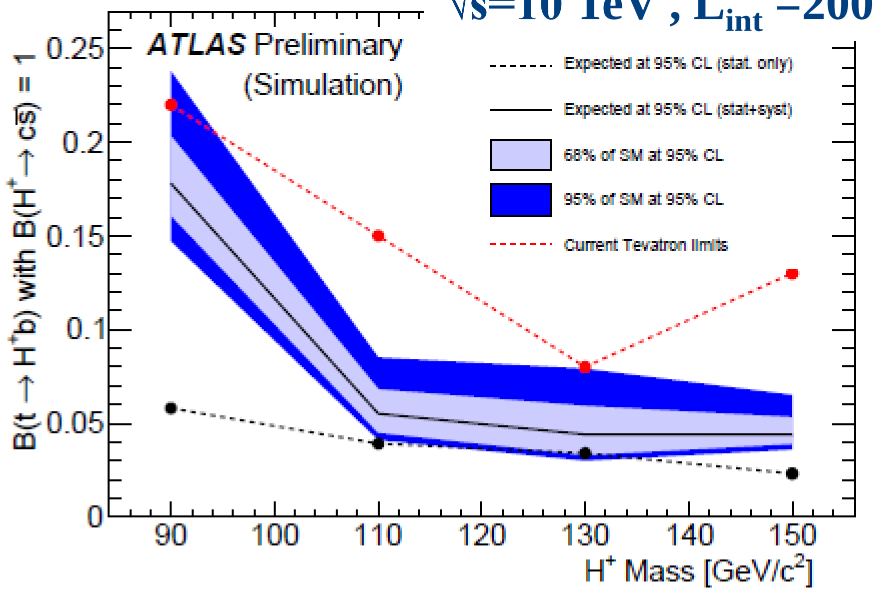
For one pseudo-experiment

with

without sytematic smearing



$\sqrt{s}$=10 TeV , L_{int} =200 pb^{-1}



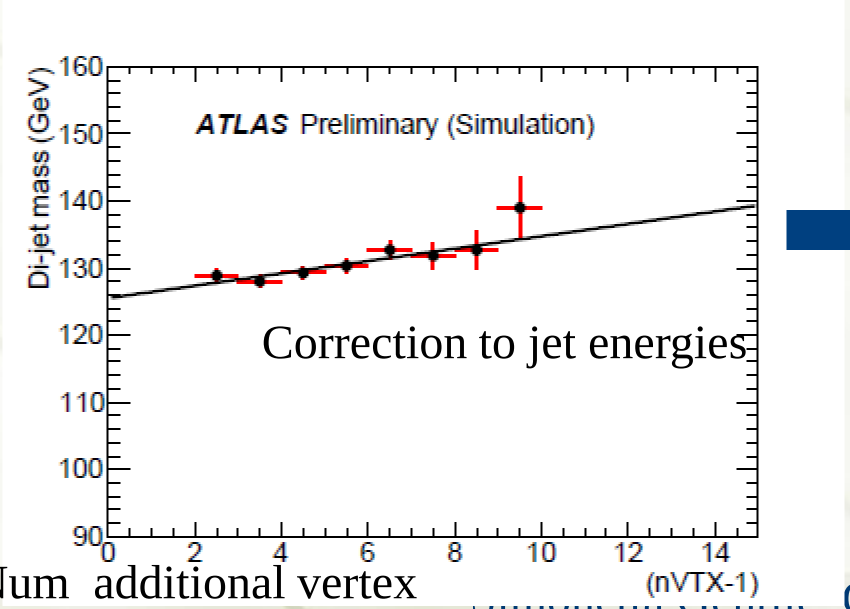
m_{H^+} (GeV)	90	110	130	150
Expected upper limit $\mathscr{B}(t \to bH^+)$ (stat. only)	5.8%	3.9%	3.4%	2.3%
Expected upper limit $\mathscr{B}(t \to bH^+)$ (stat + syst)	17.8%	5.5%	4.4%	4.3%

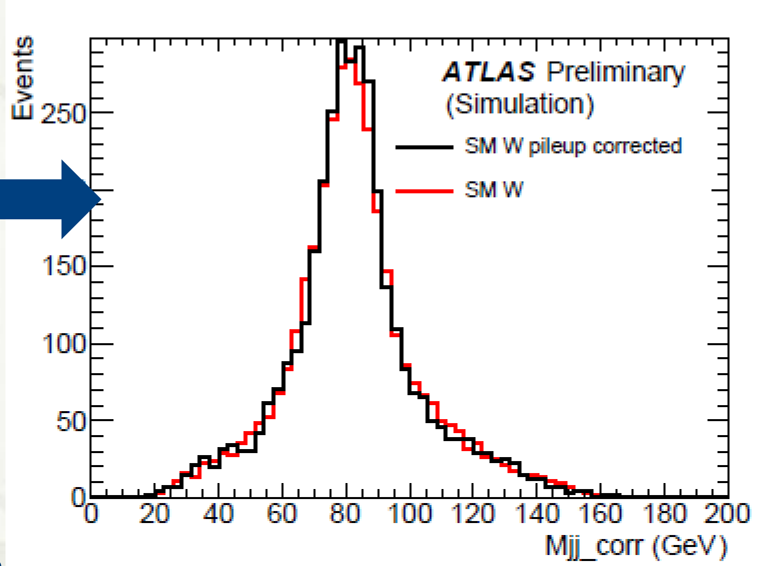
- ✦ The expected limit is higher when $M_H \rightarrow M_W$.

difficult to disentangle signal & background distribution.

Pile-up

- At **L =10 [32] cm[-2] s[-1]** in addition **4 additional interactions** (on average)
- **Increasead jet energy ⟶ shift of template dijet distribution at higher mass , used in LH fit ⟶ Br**
- **Correction to jet energies (- 920 MeV for each Vertex)**





Pile-up systematic

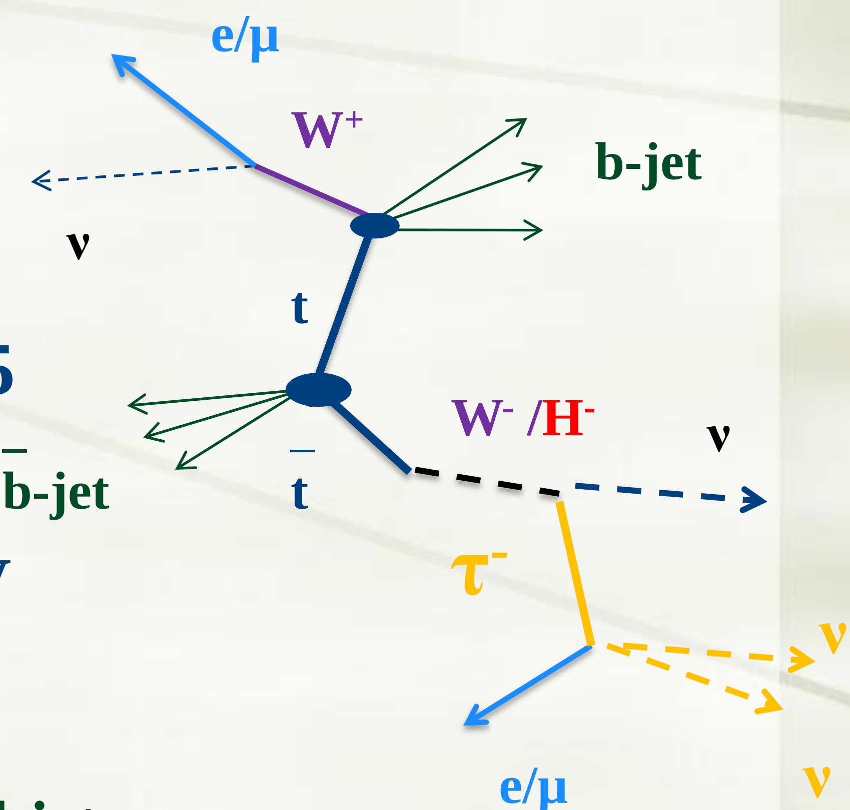
- After jet recalibration the systematic error due to pile-up 0.090 (M_H=90GeV) and 0.004 (M_H=130GeV), <0.001 for higher mass.
- The pile-up effect is not neglegible (9%) for $M_H \sim M_w$ but only 0.4% at M_H =130 GeV
- Pile-up effect not easy forseen depends from beam condition. This is a guess...

H^+ mass	Expected upper limit $\mathscr{B}(t \to bH^+)$ With pile-up	Without pile-up
90 GeV	20.8%	17.8%
130 GeV	4.5%	4.4%

Dilepton channel $H^{\pm} \rightarrow \tau\nu \rightarrow \ell^{\pm}\nu\nu\nu$

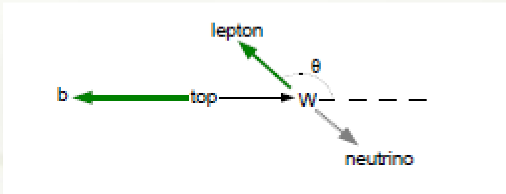
$\tan\beta > 3$

- Event **counting analysis**.
- **Analysis method:(keypoints)**
- **2 opposite charge ℓ (= e,μ):**
  p_T> 20 GeV, 10 GeV |η| <2.5
- **E_T^{miss} >50 GeV**
- **At least 2 jets, p_T> 15GeV |η| <5, b-tagged**



Problem: **Correct pairing lepton-bjets**

*Helicity angle cos θ**



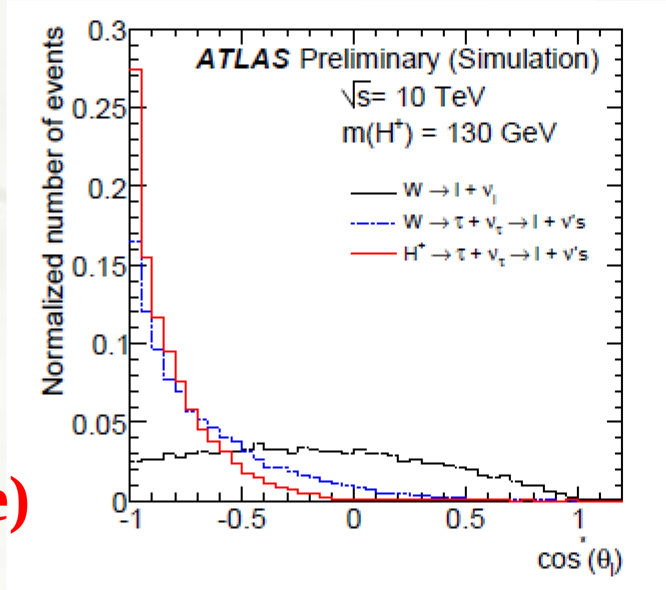
- Discriminative variable θ*

Angle of lepton wrt helicity axis, i.e.b-quark

$$\cos\theta_\ell^* \simeq \frac{4\, p_b \cdot p_\ell}{m_t^2 - m_W^2} - 1,$$

ℓ=e,μ

- H^+ is scalar (isotropic decay)
- W^+ spin-1 particle
- H^+ heavier W+
- H^+ mediated by τ

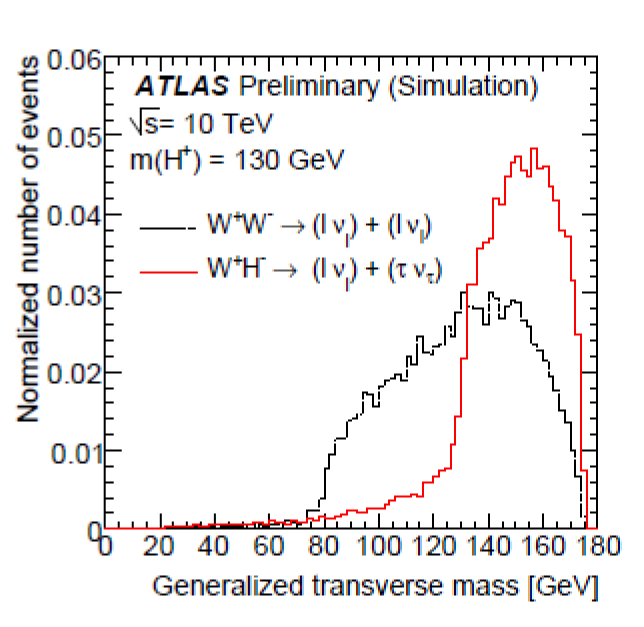


Selection Criterion cos θ* <-0.6 (H^+ side)

Generalized transverse mass M_{T2}^{H+}

$$(p^{H^+} + p^b)^2 = m_{top}^2,$$
$$(p^{\ell^-} + p^{\bar{\nu}_\ell})^2 = m_W^2,$$
$$(p^{\ell^-} + p^{\bar{\nu}_\ell} + p^{\bar{b}})^2 = m_{top}^2,$$
$$(p^{\bar{\nu}_\ell})^2 = 0,$$
$$\vec{p}_T^{H^+} - \vec{p}_T^{l^+} + \vec{p}_T^{\bar{\nu}_\ell} = \vec{p}_T^{miss}.$$

- Event-by-event upper limit of the Higgs boson mass.
- 8 variables and 6 constrains constrains
- p^{H+} and $p^{\nu\,\ell}$ unknown quantities
- Assign p^{H+} to be one of the unconstrained degrees of freedom
- Maximize H^+ mass using the Lagrange multiplier



$$m_{T2}^{H^+} = \max_{\vec{p}_T^{H^+}} [M_T^H(\vec{p}_T^{H^+})],$$

by construction

$$m_{T2}^{H^+} \geq m_{H^+}$$

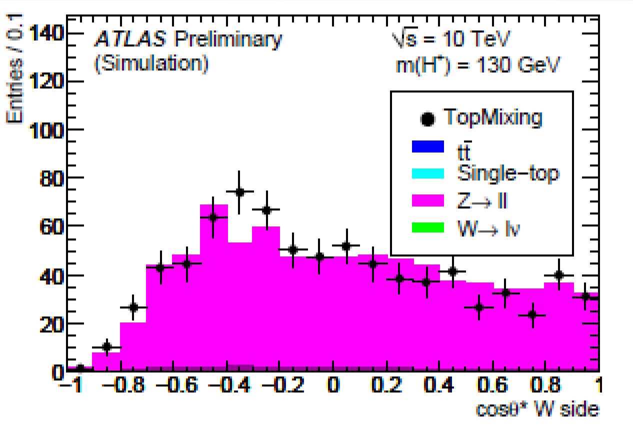
$$(M_T^H)^2 = \left(\sqrt{m_{top}^2 + (\vec{p}_T^{H^+} + \vec{p}_T^b)^2} - p_T^b\right)^2 - (p_T^{H^+})^2$$

Backgrounds

- Due to theoretical & experimental uncertainties, it is preferable not rely totally to MC simulation.
- **Normalizazion.** Scale N_{MC} to match experimental data for various background individuallyin in unique **sideband (not sensitivive to other process).**
- **The contamination of fake leptons .**

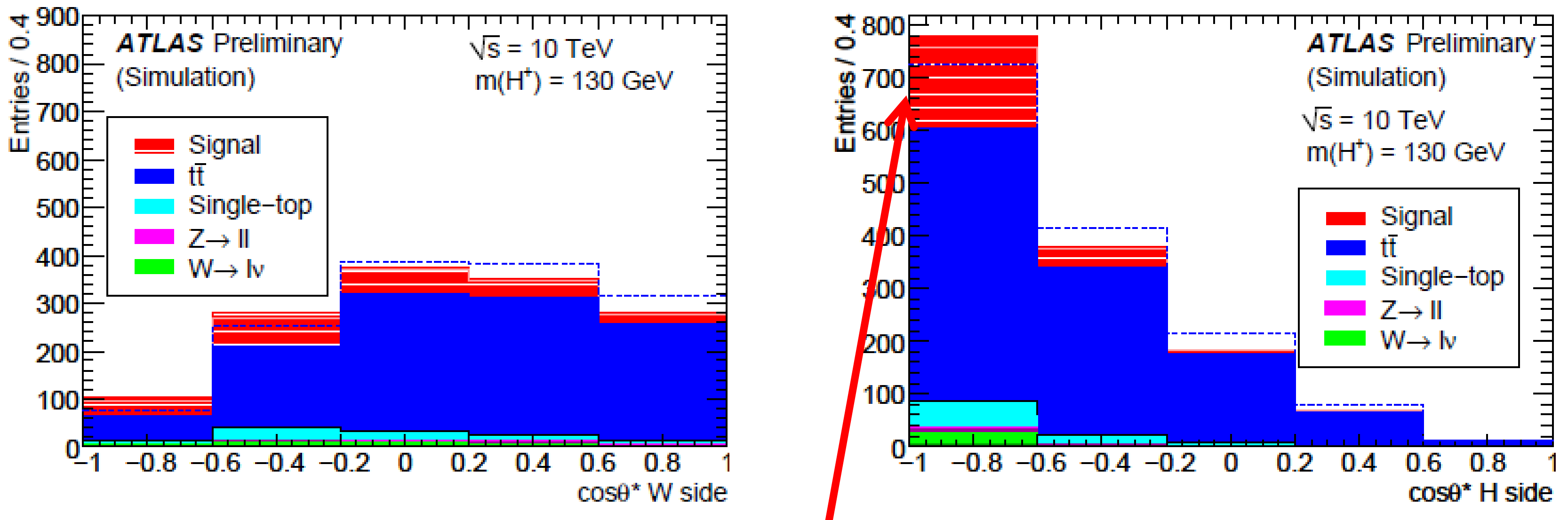
Can be determined experimentally using a "tag & probe" approach and a stringent, *thight* and less stringent, *loose* identification criteria.

The results are consistent with MC estimation



Zsideband
scaled MC sample

Sensitivity Estimation



H^+ mass in GeV	90	110	130	150
$\mathscr{B}(t \to bH^+)$	15%	15%	17%	19%
$\mathscr{S} = N_{\text{sig}}/\sqrt{N_{\text{bg}}}$	8.9	10.4	11.7	11.3

Assuming Tevatron upper limit

Upper Limits

- **No H^+ signal**

$$\mathscr{B} = \frac{N_{obs} - N_{bg}}{2 \times \sigma_{t\bar{t}} \times L_{int} \times \varepsilon_{sig}}$$

- 10000 MC toy experiment varying input parameter

Within their uncertainties. For each value

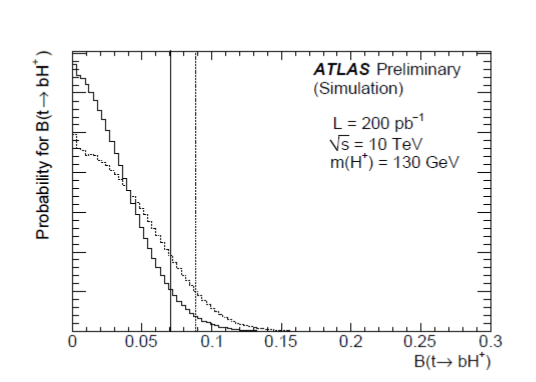
probabilty weight $W_{\mathscr{B}}(N_{bg}, N_{obs}, \varepsilon_{sig}) = P(N_{bg}) \times P(N_{obs}) \times P(\varepsilon_{sig})$

$P(x)$ Gaussian probability density function

N_{obs} Poisson uncertainty witdh $\sqrt{N_{obs}}$, N_{bg} ε_{sig} MC statistics and systematics

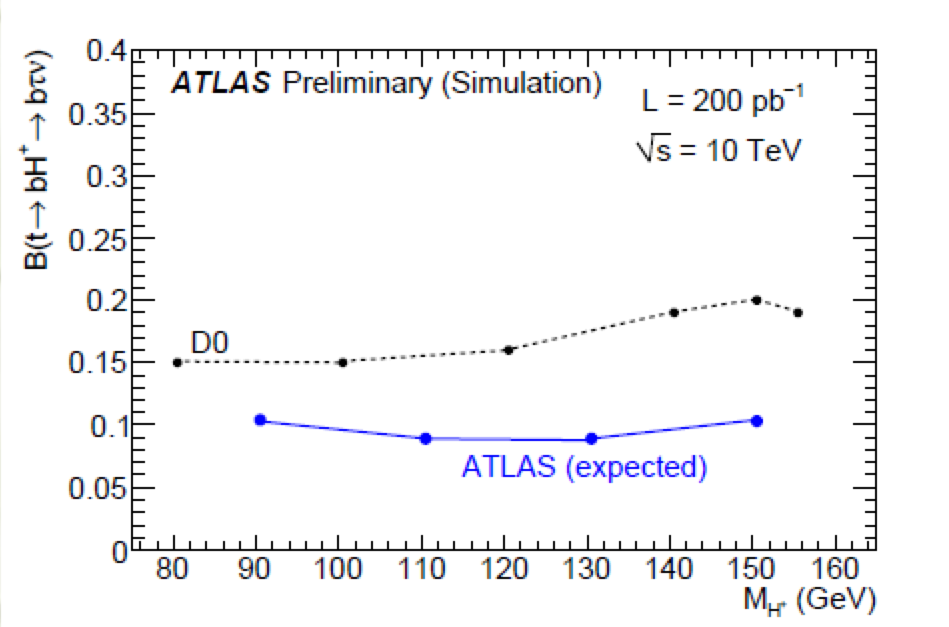
$$0.95 = \int_0^{\mathscr{B}^{95\%}} \mathscr{B} d\mathscr{B}.$$

In case of non observation of signal $(N_{obs} - N_{bg} = 0)$



Upper limits

Mass (GeV)	Signal Efficiency	Expected upper limit on $\mathscr{B}(t \to bH^+)$ without systematics	with systematics
90	11.0%	8.3%	10.4%
110	12.8%	7.1%	8.9%
130	12.7%	7.1%	8.9%
150	11.1%	8.0%	10.3%



Systemic Uncertainties

- N_{bg} , ε_{sig} (signal efficiency) may be affected by systematic uncertainties at theoretical level and detector performance.
- The background MC samples are normalized to data, many

uncertainties don't affect the expected number of background events .

- **Data driven method** not sensitive to δL_{int}
- **reduce δσ** for signal & background model -dependent

and varying with√**s, to 7**%(depending from MC and data statistics). Additional < 1% due to relative uncertainty

single top/ttbar σ

Systematic Uncertainties

- **Trigger & lepton reconstruction efficiency 1%** (arXiv:0901.0512)
- **Energy scale for lepton 1%,** mainly from faking electrons (in calculation of faking elctron efficiency)
- **Jet energy scale 7% $|\eta| < 3.2$ and 15% $|\eta| > 3.2$** (p_T requirement, $\cos\theta^*$)
- **E_t^{miss}** is affected by lepton and energy scale. **Neglegible.** ttbar process is normalized after the cut on E_t^{miss}
- **b-tag** $\varepsilon_b = 60\%$, $\delta\varepsilon_b = 4\%$. The fake rejection rate Z/W+jets and QCD ⟶ additional 10%

Systematic Uncertainties

- **Theoretical uncertainty**: ttbar AcerMC and MC@NLO
- ISR/FSR not relevant no cut on jet multelpicity.

Source	Uncertainty (in %)	Effect (in %) on N_{bg}	Effect (in %) on ε_{sig}
Normalization	7	7	n/a
Trigger	1	< 1	1
Lepton ID efficiency	1	< 1	1
Lepton fake rate	1	1	1
Lepton energy scale	1	< 1	1
Jet energy scale	7-15	7	4
b-tagging efficiency	4	< 1	4
b-tagging fake rate	10	1	< 1
Total		10	6

Pile-up

Without Pile-up $\mathcal{B}(t \to bH^+) = 10\%$

Process	Number of events after					
	no cut	$2l+2j$	b-tagging	E_T^{miss}	$\cos\theta_l^*$	Trigger
Signal $m_{H^+} = 90$ GeV	1286	378	300	211	151	141
Signal $m_{H^+} = 130$ GeV	1286	405	308	221	173	163

With Pile-up

Process	Number of events after					
	no cut	$2l+2j$	b-tagging	E_T^{miss}	$\cos\theta_l^*$	Trigger
Signal $m_{H^+} = 90$ GeV	1286	395	310	219	154	147
Signal $m_{H^+} = 130$ GeV	1286	430	321	232	178	170

- At **L =10 ^{32} cm^{-2} s^{-1}** Pile-up doesn't affect significantly the results

Running at √s=7 TeV $H^{+} \longrightarrow$ *csbar*

- σ_{ttbar} =161 pb at √s=7 TeV σ_{ttbar} = 401.6 pb at √s=10 TeV ⟶ factor ~ 2
- Using the same analysis procedure of √s=10 TeV
- **Assuming same cut efficiencies** at 7 TeV and 10 TeV

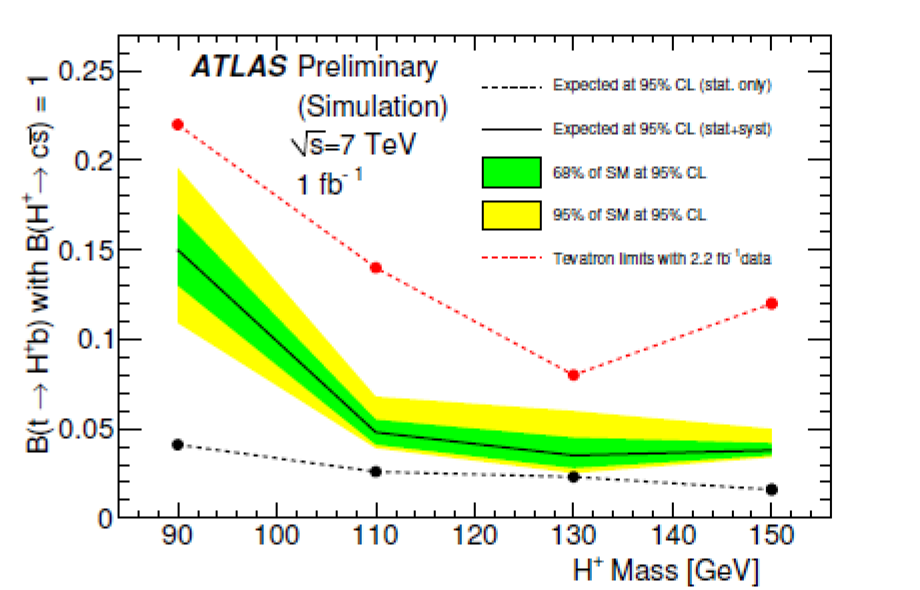
At M_H=130 GeV

Systematic	$\pm 1\sigma$	$\Delta\mathscr{B}$
Jet Energy Resolution	$0.45 * \sqrt{E}$ ($\|\eta\| < 3.2$), $0.63 * \sqrt{E}$ ($\|\eta\| > 3.2$)	0.73×10^{-2}
Jet Energy Scale	±7% ($\|\eta\| < 3.2$), ±15% ($\|\eta\| > 3.2$)	0.04×10^{-2}
MC Generator	MC@NLO vs AcerMC	0.47×10^{-2}
ISR/FSR	ISR/FSR More vs Less	0.40×10^{-2}
b-jet Energy Scale	±3%	0.75×10^{-2}
Lepton Energy Scale	±1%	0.12×10^{-2}
Combination	In quadrature	1.2×10^{-2}

Upper Limits

$\sqrt{s}$=7 TeV L_{int}= 1fb^{-1}

m_{H^+} (GeV)	90	110	130	150
Expected upper limit $\mathcal{B}(t \to bH^+)$ (stat. only)	4.0%	2.5%	2.3%	1.5%
Expected upper limit $\mathcal{B}(t \to bH^+)$ (stat + syst)	14.8%	4.7%	3.4%	3.7%



Simonetta Gentile, Charged Higgs, 2010,Uppsala, Sweden.

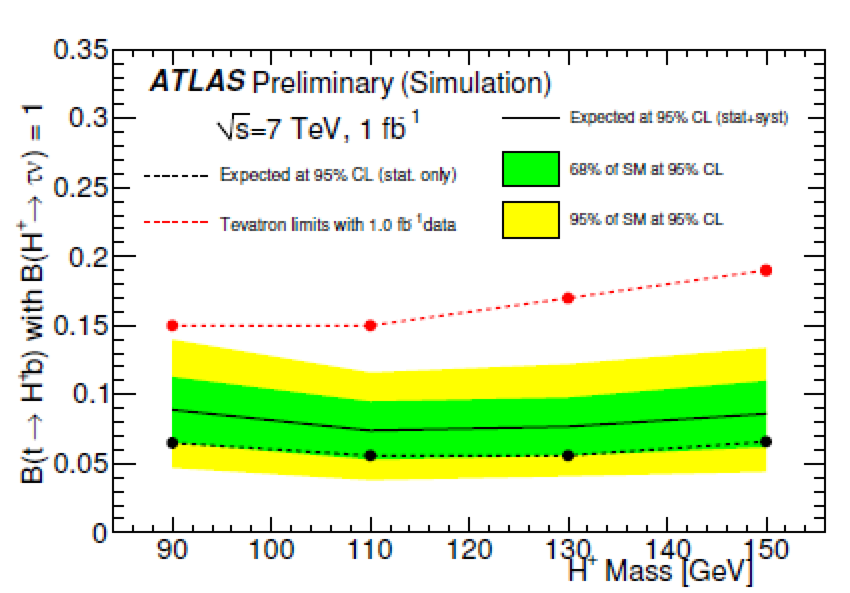
Running at √s=7 TeV $H^+ \longrightarrow \tau^+\nu$

- Using the same analysis procedure of √s=10 TeV
- **Assuming same cut efficiencies** at 7 TeV and 10 TeV

sensititvity

H^+ mass in GeV	90	110	130	150
$\mathscr{B}(t \to bH^+)$	15%	15%	17%	19%
$\mathscr{S} = N_{sig}/\sqrt{N_{bg}}$	12.3	14.4	16.0	15.5

Mass (GeV)	Expected upper limit on $\mathscr{B}(t \to bH^+)$ without systematics	Expected upper limit on $\mathscr{B}(t \to bH^+)$ with systematics
90	6.5%	8.9%
110	5.6%	7.4%
130	5.6%	7.7%
150	6.6%	8.6%



Upper Limits and Conclusions

$\sqrt{s}$=7 TeV L_{int} =1fb^{-1} $\mathscr{B}(t \to bH^+)$

at 95%CL (with systematics) | without systematics

m_{H^+} (GeV)	$H^+ \to \tau^+\nu$ Tevatron	$H^+ \to \tau^+\nu$ ATLAS expected	without systematics	$H^+ \to c\bar{s}$ Tevatron	$H^+ \to c\bar{s}$ ATLAS expected	without systematics
90	15%	9%	6.5%	22%	15%	4.0%
110	15%	7%	5.6%	15%	5%	2.5%
130	17%	8%	5.6%	8%	3.4%	2.3%
150	19%	9%	6.6%	13%	3.7%	1.5%

$\mathscr{B}(H^+ \to \tau^+\nu) = 1$ $\mathscr{B}(H^+ \to c\bar{s}) = 1$

- Sensitivity studies suggest that the Tevatron limit on (**Br(t ⟶ H$^+$ b)**) branching ratio can significantly be improved during the early data taking period (end 2011).
- But...... A **particular attention to systematic** studies has to be deserved. Its impact can lead up to a factor of 2-3 degredation on the measured limits.