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ATLAS Sensitivity Prospects for Light Charged Higgs Searches at 7 TeV

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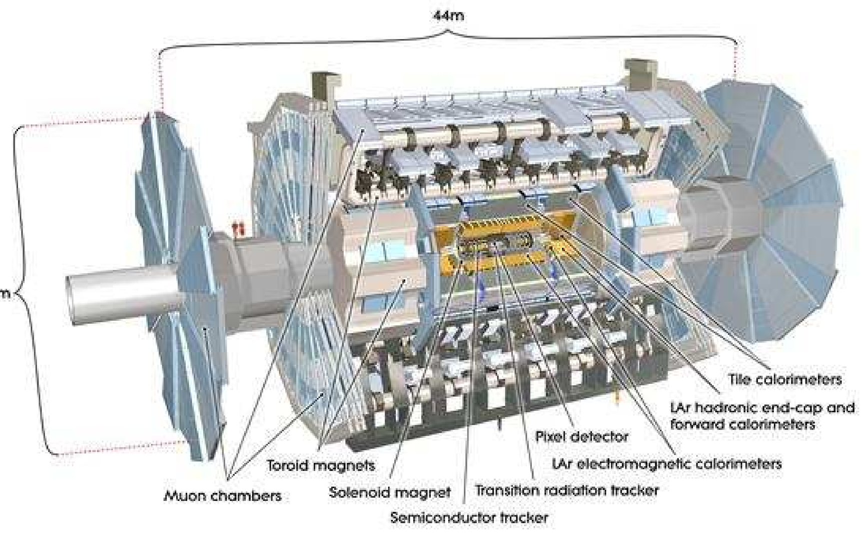
ATLAS EXPERIMENT

The LHC and the ATLAS experiment

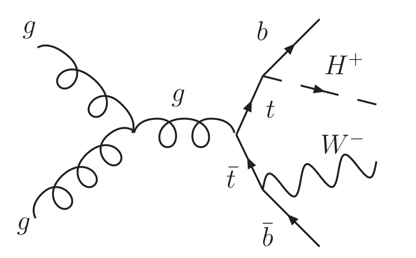
The Large Hadron Collider (LHC) is a proton-proton collider situated at the CERN research facility near Geneva, Switzerland. It is currently delivering collisions at a centre-of-mass energy of 7 TeV and is aiming to provide $1\ \mathrm{fb}^{-1}$ of luminosity by the end of 2011.

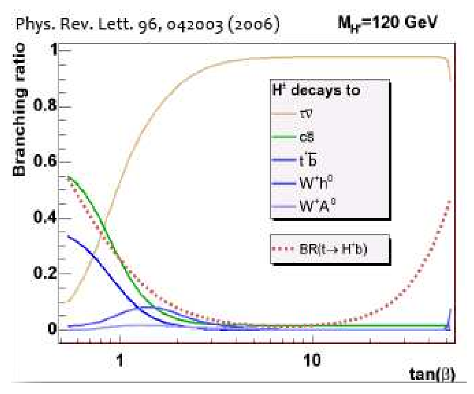
ATLAS (A Toroidal Large ApparatuS) is a general-purpose detector designed to exploit the data produced by the LHC to study a wide variety of physics, including searches for Higgs bosons.



Light charged Higgs searches at the LHC

- Charged Higgs bosons are predicted in various extensions of SM with more than one Higgs doublet (e.g., MSSM). Discovery of a charged Higgs boson would be a definite signal for new physics beyond SM.
- Light H^+ ($m_{H^+} < m_{\mathrm{top}}$) are produced primarily through top decays $t \to H^+ b$ (charge conjugate states are implied throughout):
  - $H^+ \to \tau^+\nu$ dominant for $\tan\beta > 3$
  - $H^+ \to c\bar{s}$ significant for low $\tan\beta$
- Search for $t\bar{t}$ event topology with one of the tops decaying to H^+ instead of W^+, while the other decays to W^- with subsequent leptonic decays:
  - Main background is SM top pair production





$H^+ \to c\bar{s}$ (semileptonic) channel

Analysis method

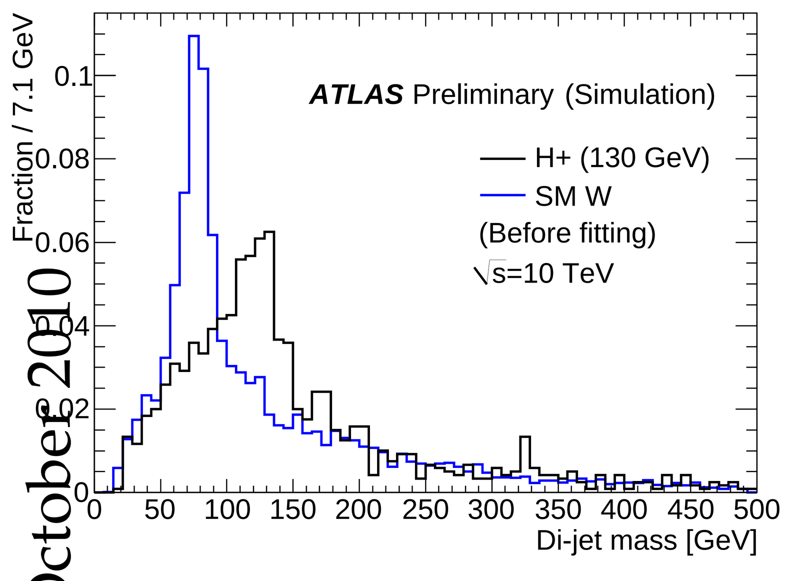
- In SM, $\mathcal{B}(t \to W^+ b) \sim 1$. If a top quark decays through a charged Higgs, i.e., $t \to H^+ b$, this would appear as a second peak in the reconstructed di-jet (W) mass distribution. Therefore, this analysis is performed by considering the shapes of the di-jet mass distributions.
  - Use di-jet mass fitter to reduce widths and tails of distributions
  - Improved distributions used as templates for extracting upper limits on branching ratios
  - Evaluated impact of sources of systematic uncertainty on selection acceptances and di-jet mass shapes:
    - Dominant systematics were jet energy resolution and b-jet energy scale
- Signature consists of:
  - High-p_T lepton trigger; electron or muon with $p_T > 15$ GeV
  - Exactly 1 lepton; $p_T > 20$ GeV, $|\eta| < 2.5$
  - 4 jets; $E_T > 20$ GeV, $|\eta| < 2.5$, 2 b-tagged
  - Missing E_T from neutrino; $E_T^{\mathrm{miss}} > 20$ GeV

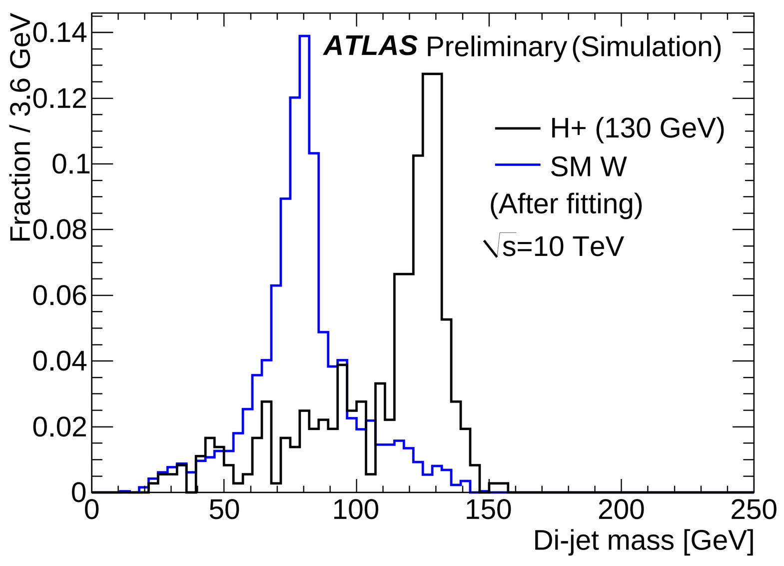
The di-jet mass fitter

- With 2 b-tags, there are 4 possible combinations of jets with partons and solutions for the longitudinal momentum of the neutrino. With 1 (0) b-tag, this number increases to 12 (24).
- To help select the best combination, the following χ^2 function (based on the CDF top mass fitter) is defined to constrain the kinematics of the $t\bar{t}$ system:

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

- The fit is also improved by allowing the measured momenta to vary within their experimental resolutions.





Signal extraction

- Assuming no charged Higgs signal, a binned maximum likelihood method has been used to extract upper limit on $\mathcal{B}\left(t \to H^+ b\right)$:

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

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

- Three fit parameters: branching ratio $\mathcal{B}\left(t \to H^+ b\right)$, total number of $t\bar{t}$ events $N_{t\bar{t}}$, number of non-$t\bar{t}$ background events N_{bkg}.
- Upper limit on $\mathcal{B}\left(t \to H^+ b\right)$ at 95% confidence level extracted based on pseudo-experiments (PEs):
  - Pseudodata generated from template distributions using bin-by-bin Poisson fluctuations
  - For each PE, $\mathcal{B}\left(t \to H^+ b\right)$ scanned over range [0,1] to find 95% positive area of integrated likelihood
  - The mean value over all PEs is defined to be the expected limit

$H^+ \to \tau_{\mathrm{lep}}^+ \nu$ (dilepton) channel

Analysis method

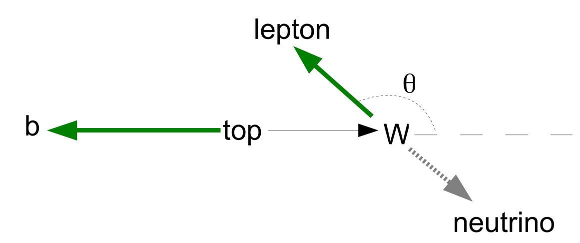
- Essentially an event counting analysis.
- Identify potential signal events using new analysis variables: helicity angle $\cos\theta^*$ and generalized transverse mass $m_{T2}^{H^+}$:
  - These variables are also used to resolve 4-fold ambiguity in assigning leptons and b-jets to their parents
- Use data-driven techniques to estimate backgrounds:
  - Sidebands to normalize backgrounds
  - Tag-and-probe to estimate the portion of non-$t\bar{t}$ background due to lepton misidentification
- Dominant systematics were background normalization, jet energy scale and b-tagging efficiency.
- Signature consists of:
  - High-p_T lepton trigger; electron or muon with $p_T > 15$ GeV
  - Two oppositely charged leptons; leading $p_T > 20$ GeV, sub-leading $p_T > 10$ GeV, $|\eta| < 2.5$
  - Large missing E_T from 4+ neutrinos; $E_T^{\mathrm{miss}} > 50$ GeV
  - 2 jets; $E_T > 15$ GeV, $|\eta| < 5$, with b-tagging

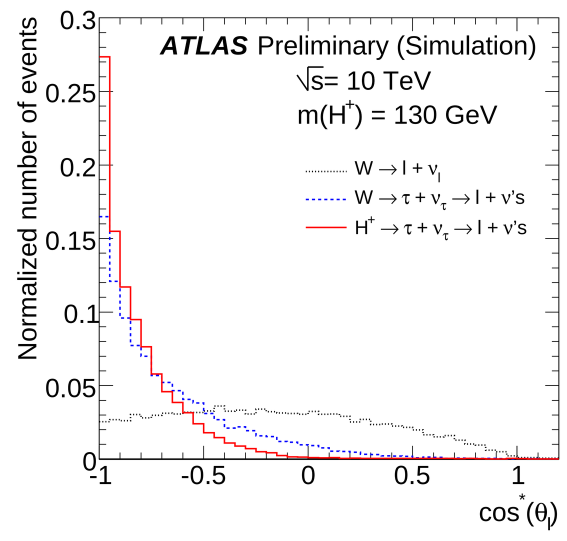
Helicity angle $\cos\theta^*$

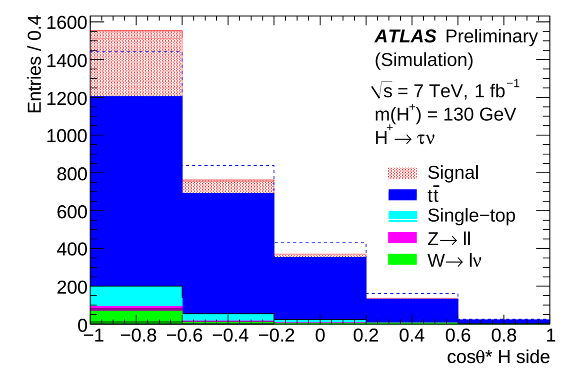
- θ^* is angle of lepton wrt helicity axis, i.e., b-quark.
- Since SM W bosons are spin-1 particles, the angle is chosen to be:

$$\cos\theta_l^* \simeq \frac{4 p_b \cdot p_l}{m_t^2 - m_W^2} - 1$$

- Distribution peaked near -1 for H^+ decays:
  - H^+ is scalar (isotropic decay)
  - H^+ heavier than W
  - H^+ decay mediated by intermediate τ







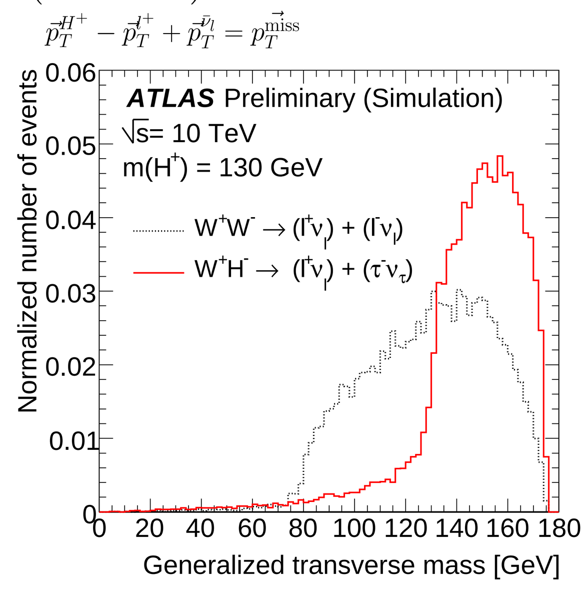
Generalized transverse mass $M_{T2}^{H^+}$

$$\left(p^{H^+} + p^b\right)^2 = m_{\mathrm{top}}^2 \qquad \left(p^{l^-} + p^{\bar{\nu}}\right)^2 = m_W^2$$
$$\left(p^{l^-} + p^{\bar{\nu}} + p^{\bar{b}}\right)^2 = m_{\mathrm{top}}^2 \qquad \left(p^{\bar{\nu}}\right)^2 = 0$$
$$\vec{p}_T^{H^+} + \vec{p}_T^{\bar{\nu}} + \vec{p}_T^{\bar{b}} = \vec{p}_T^{\mathrm{miss}}$$

- Event-by-event upper limit for mass of the Higgs boson:
  - 8 variables and 6 constraining equations
  - p^{H^+} and $p^{\bar{\nu}_l}$ represent unknown quantities
  - Assign $p_z^{H^+}$ to be one of the unconstrained degrees of freedom
  - Maximize H^+ mass using the Lagrange multipliers:

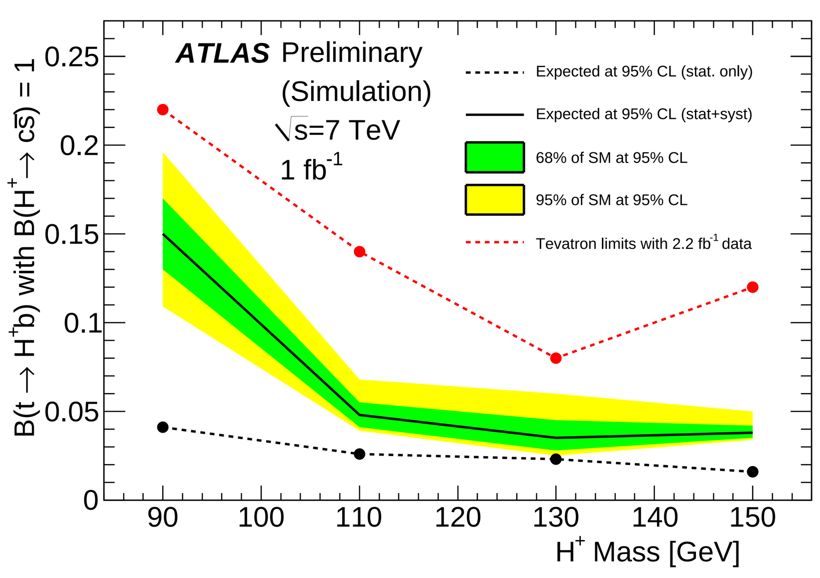
$$m_{T2}^{H^+} = \max_{\vec{p}_T^{H^+}} \left[M_T^H\left(\vec{p}_T^{H^+}\right) \right]$$

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



Sensitivity estimation

- Assuming no charged Higgs signal, $\mathcal{B}\left(t \to H^+ b\right)$ is calculated according to $\mathcal{B} = \frac{N_{\mathrm{obs}} - N_{\mathrm{bg}}}{2 \times \sigma_{t\bar{t}} \times \mathcal{L}_{\mathrm{int}} \times \varepsilon_{\mathrm{sig}}}$.
- The upper limit evaluation on $\mathcal{B}\left(t \to H^+ b\right)$ at 95% confidence level based on toy MC experiments:
  - Vary input parameters according to Gaussian distribution
  - Calculate branching ratio for each toy MC
  - Limits are established through a Bayesian integral with flat prior in signal strength



Summary and conclusions

In various models beyond the Standard Model, including the Minimal Supersymmetric Model (MSSM), charged Higgs bosons can be produced through top quark decays $t \to H^+ b$. The ATLAS sensitivity studies for the light charged Higgs in two dominant MSSM decay channels, viz. $H^+ \to \tau^+\nu$ and $H^+ \to c\bar{s}$, have been presented here. With $1\ \mathrm{fb}^{-1}$ of proton-proton collision data at 7 TeV, the ATLAS upper limits on $\mathcal{B}\left(t \to H^+ b\right)$ are expected to improve substantially over the current Tevatron limits.

The material presented here was based on ATLAS notes ATL-PUB-2010-006 and ATL-PUB-2010-009.