PROCEEDINGS OF SCIENCE

Improved sensitivity to charged Higgs searches un top quark decays $t \to bH^+ \to b(\tau^+\nu_\tau)$ at the LHC using τ polarisation and multivariate techniques

Javier Llorente[*†]
Universidad Autónoma de Madrid
E-mail: javier.llorente.merino@cern.ch

We develope a search method for MSSM charged Higgs bosons $H^\pm$ at the LHC using its decay to a neutrino and a τ lepton, which is then left to decay hadronically via $\tau^\pm \to \rho^\pm\nu_\tau \to \pi^\pm\pi^0\nu_\tau$. To this end, we use some observables such as the fraction of energy carried by the charged pion track with respect to the total τ-jet energy and the cosine of the helicity angle ψ. These variables are then reprocessed using multivariate methods (Boosted Decision Tree) implemented on TMVA.

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*Speaker.

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1. Theoretical background

The Higgs sector of the Minimal Supersymmetric Standard Model (MSSM) is composed of two Higgs doublets, Φ_u, Φ_d with different vacuum expectation values, v_u, v_d respectively, which are related by $\tan\beta = v_u/v_d$. This leads to five different Higgs particles, namely A^0, h^0, H^0 and $H^{\pm}$. On this work, we focus on the last ones, $H^{\pm}$, which can be produced at the LHC via the top quark decays $t \to H^+ b$. The relevant part of the interaction Lagrangian can be written as:

$$\mathscr{L}_{H^+} = \frac{g}{\sqrt{2}M_W} H^+ \left[\cot\beta V_{ij} m_{u_i} \bar{u}_i P_L d_j + \tan\beta V_{ij} m_{d_j} \bar{u}_i P_R d_j + \tan\beta m_{l_j} \bar{\nu}_j P_R l_j\right] + h.c. \qquad (1.1)$$

Where V_{ij} are the CKM flavour mixing matrix elements. If we focus on the leptonic term, we see that H^+ couples to right-handed leptons, whereas in the Standard Model (SM), the W bosons couple to the leptons via the charged current interaction Lagrangian, which involves only left-handed leptons:

$$\mathscr{L}_{CC} = \frac{g}{\sqrt{2}M_W} W^+_\mu \left[\bar{\nu}_j \gamma^\mu P_L l_j + V_{ij} \bar{u}_i \gamma^\mu P_L d_j\right] + h.c. \qquad (1.2)$$

Where P_L and P_R are the left-right chirality operators, defined as $P_{R,L} = \frac{1}{2}(1 \pm \gamma_5)$. These differences on the couplings lead to different angular distributions of the τ decay products, which will be exploited on our analysis.

2. Relevant observables

In this section we describe the measurable quantities at the multi-purpose detectors installed at the LHC. The goal is to measure those quantities and reprocess them using TMVA. Some of them have already been used in recent cut-based analysis (see [2]) exploring this channel. The signal and background events for top pair and single top production have been generated using Pythia 6.4. The diagrams for $t\bar{t}$ are shown in figure 1.

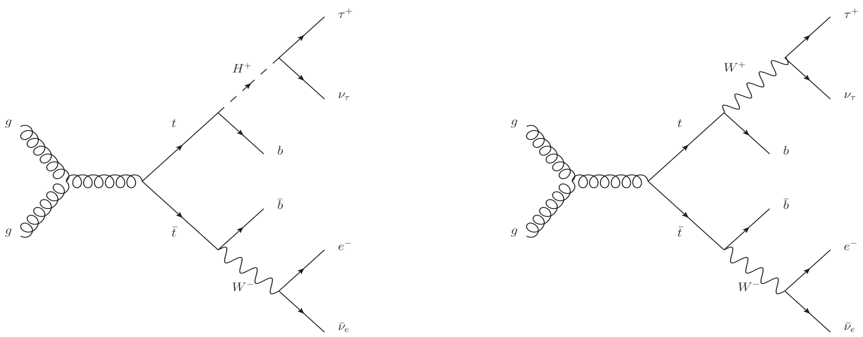

Figure 1: Signal and SM irreducible background processes for $t \to H^+ b$

2.1 Helicity angle ψ

The helicity angle is defined as the angle between the outgoing direction of the top quark and the ρ meson in the reference frame where the W boson (or the H^+ in our case) is at rest. It can be aproximated by the following expression:

$$\cos\psi = -\frac{\vec{p}_t \cdot \vec{p}_\rho}{|\vec{p}_t||\vec{p}_\rho|} \simeq \frac{2m_{\rho b}^2}{m_t^2 - m_W^2} - 1 \tag{2.1}$$

The distributions for $\cos\psi$ for H^+ masses of 90, 110, 130 and 150 GeV, as well as for the SM background $t \to W^+ b$ are shown in figure 2

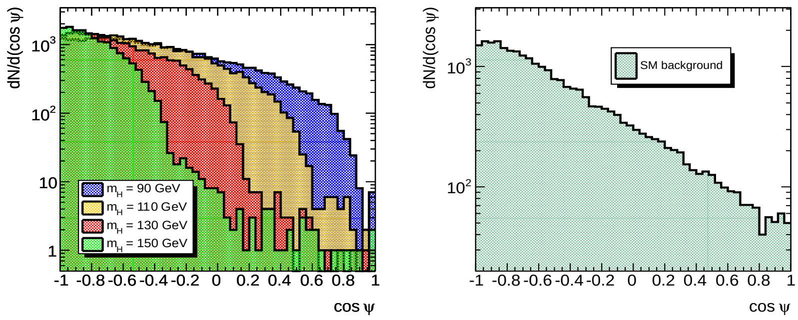

Figure 2: $\cos\psi$ for different H^+ masses and the SM background

2.2 τ energy ratio

Another observable which could help in the classification of H^+ events is the energy and p_T ratio from the track of the pion in the τ-jet and the τ-jet itself, this is, the ratios

$$\lambda_e = \frac{E_\pi}{E_\rho}; \quad \lambda_p = \frac{p_T^\pi}{p_T^\rho} \tag{2.2}$$

In this study, we only allow τ leptons to decay via the 1-prong channel $\tau \to \rho \nu_\tau \to \pi^+ \pi^0 \nu_\tau$, so we take the energy and transverse momentum of the track from the charged pion and divide it by the transverse momentum of the τ-jet (the ρ meson). The distributions for these variables are shown in figure 3

2.3 τ-jet energy ratio to b-jet energy

As the H^+ in this study is heavier than the W, τ-jets coming from massive Higgs bosons are harder than τ-jets coming from W bosons. On the other hand, the b-jets coming from the W^+ production vertex are harder than the ones coming from H^+ vertices. Therefore, a good discriminating variable would be the ratio from the τ-jet energy and p_T to the corresponding b-jet kinematical quantity. The distributions are shown in the right parto of figure 3. The identification of this b-jet (there are two in every event) could be done assuming topological correlations between the H^+ decay products (the τ-jet) with respect to the b-jet. This is, there exist a correlation in the distance $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$ between the b-jet from the H^+ production vertex and the τ-jet from the H^+ decay. Another possible identification method for this b-jet makes use of the fact that the b-jet

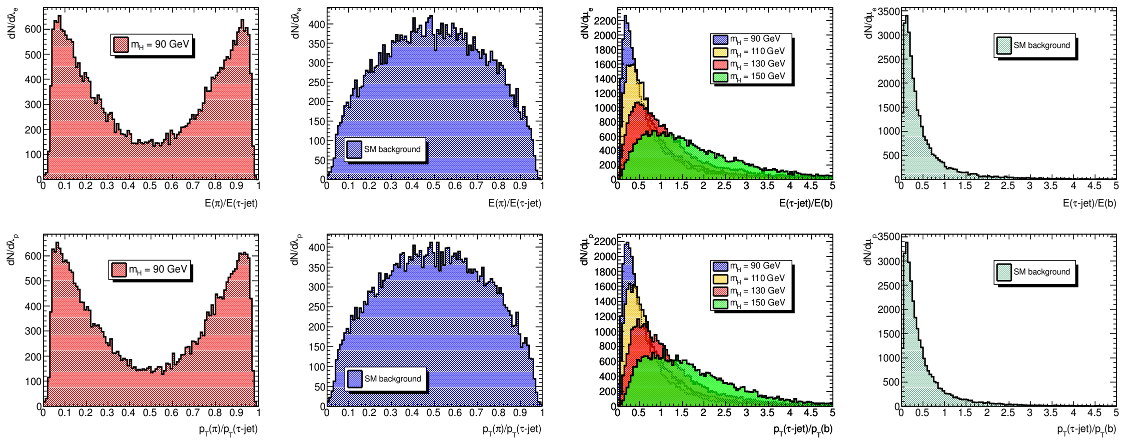

Figure 3: Energy and momentum ratio from the pion to the τ-jet. Ratio τ to b energy and p_T

coming from the H^+ vertex has opposite charge to the charged pion from the τ decay. Defining the jet charge as (see [3])

$$Q_{jet} = \frac{\sum_i (p_L^{(i)})^\alpha q_i}{\sum_i (p_L^{(i)})^\alpha}; \quad \alpha = \frac{1}{2} \tag{2.3}$$

Where the index i covers all the tracks within the jet cone with longitudinal momentum $p_L^{(i)}$ with respect to the jet axis and charge q_i. The value of α is derived from optimization methods to give a maximum separation between b and $\bar{b}$ jets.

3. H^+ production in the single top channel

The single top channel has the advantage that the mass of the charged Higgs boson can be measured. We define the W transverse mass as

$$m_T^W = \sqrt{2 p_T^\tau E_T^{miss} (1 - \cos\Delta\phi)} \tag{3.1}$$

This variable gives a good discrimination between signal and background, but does not help to measure the actual H^+ mass. To avoid this, we define (see [6])

$$(m_T^H)^2 = \left(\sqrt{m_t^2 + (\vec{p_T}^l + \vec{p_T}^b + \vec{p_T}^{miss})^2} - p_T^b \right)^2 - (\vec{p_T}^l + \vec{p_T}^{miss})^2 \tag{3.2}$$

The distributions for the variables defined in equations 3.1 and 3.2 are shown in figure 4

4. TMVA results

Once we have these variables simulated for the signal and background processes, we use them to train a Boosted Decision Tree (BDTD) in order to give the best separation between the signal and background processes. The classification of a given event would be done attending to these distributions. We do this separately for the ttbar and single top processes.

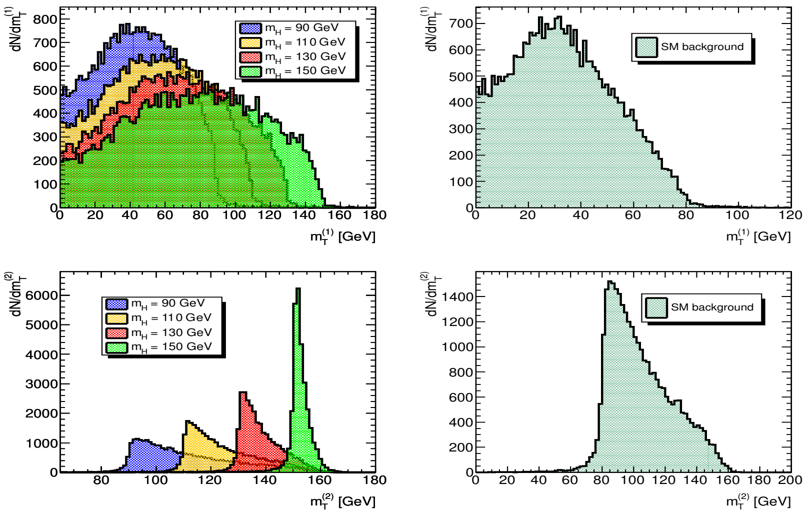

Figure 4: Transverse masses for the W and charged Higgs

4.1 Top pair production

For the ttbar channel, TMVA provides a good discrimination between H and W charged bosons. Figure 5 shows the BDTD output distributions for the signal and background processes in this channel (left) and the ROC curves, efficiency versus background rejection (right).

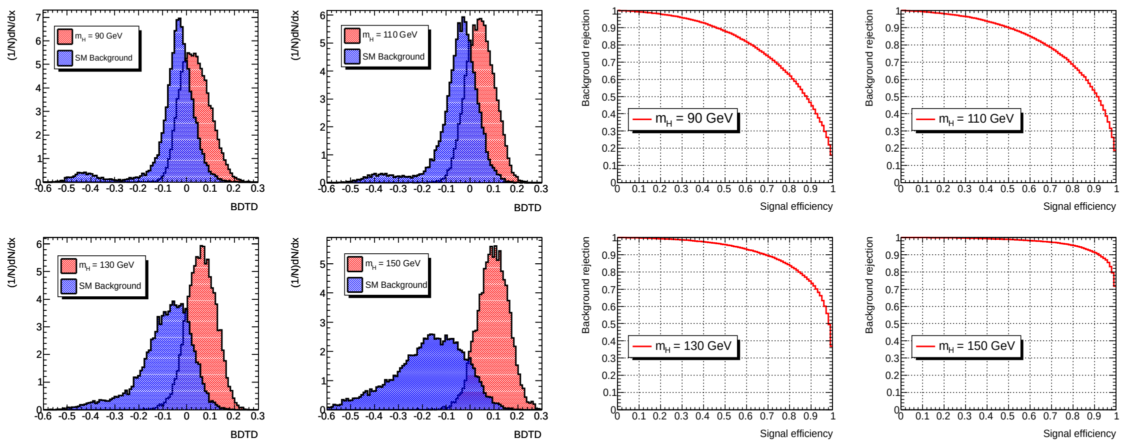

Figure 5: BDTD outputs for the ttbar channel

4.2 Single top production

The single top channel achieves a better discrimination, as the mass distributions provides the highest separation between the two processes. Figure 6 shows the BDTD outputs for each mass (left) and the ROC curves (right). As it is seen in figure 5, for the $t\bar{t}$ channel we find that for the less favorable case ($m_H = 90$ GeV), a background rejection of 90% can be achieved with a 50% signal

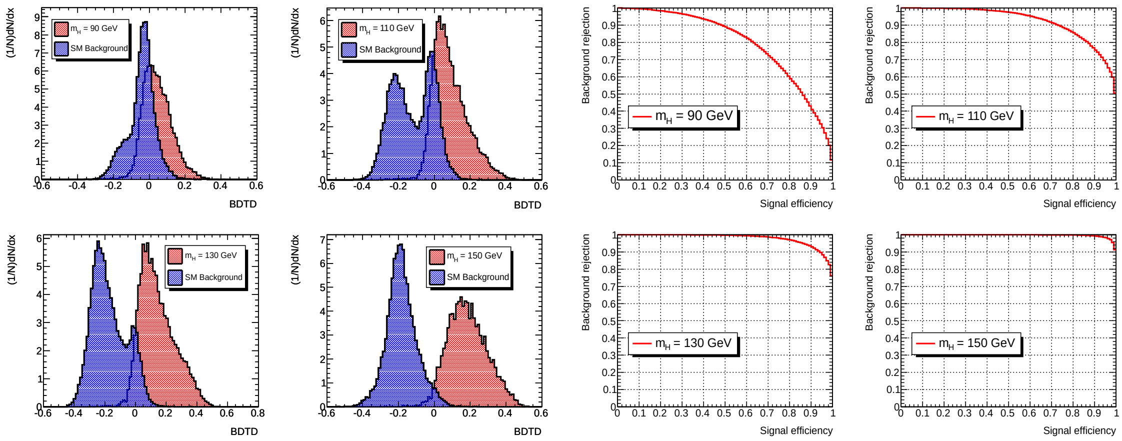

Figure 6: BDTD outputs for the single top channel

efficiency. Considering the less preferred case $\tan\beta = 10$, we get a branching fraction $\mathscr{B}(t \to H^+b) \simeq 0.02$ (see [7]). Taking into account the fact that for a center of mass energy of $\sqrt{s} = 14$ TeV the $t\bar{t}$ cross section is $\sigma_{t\bar{t}} \simeq 874$ pb, with an integrated luminosity of 10 fb^{-1}, one will get $2 \cdot 10^4$ signal events and 10^5 background events, where the production via the two possible charge conjugate final states has been taken into account with a factor of 2. The expected significance, with a 90% background rejection vs 50% efficiency for the $t\bar{t}$ channel would be

$$S = \frac{N_{signal}}{\sqrt{N_{background}}} \simeq \frac{10^4}{\sqrt{10^4}} = 100$$

For a center of mass energy of $\sqrt{s} = 7$ TeV, the cross sections are reduced in a factor of 4, what means that our expected significance will reduce in a factor of 2.

An analogous calculation for the single top channel ($\sigma \simeq 200$ pb at $\sqrt{s} = 14$ TeV) yields to a significance of $S \simeq 85$, which will be reduced by trigger and acceptance cuts in a more realistic calculation.

To summarize, we believe that if a light H^+ as expected in the MSSM exists, we will not miss it, by looking at the one prong hadronic τ decays, for any value of $\tan\beta$.

References

[1] A. Ali, F. Barreiro, J.Llorente, [arxiv:1103.1827 (hep-ph)]

[2] The ATLAS Collaboration [JHEP 1206 (2012) 039]

[3] The ATLAS Collaboration [arXiv:0901.0512 (hep-ex)].

[4] The ATLAS Collaboration, ATLAS-NOTE ATL-PHYS-PUB-2010-006 (2010).

[5] The ATLAS Collaboration, ATLAS-NOTE ATL-PHYS-PUB-2010-003 (2010).

[6] E. Gross, O. Vitells, Phys. Rev. D81, 055010 (2010). [arXiv:0907.5367 (hep-ph)].

[7] A. Sopczak, PoS CHARGED2008, 023 (2008). arXiv:0907.1498 [hep-ph]