

# Improved sensitivity for Charged Higgs searches in Top quark decays using $\tau$ polarisation and Multivariate Analysis

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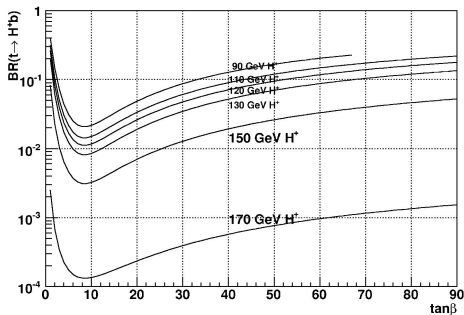
Charged Higgs 2012, Uppsala

We present a method to search for a light charged Higgs  $H^\pm$  from the decay chain  $t \rightarrow bH^+ \rightarrow b\tau^+\nu_\tau$ . The relevant part of the MSSM Lagrangian is

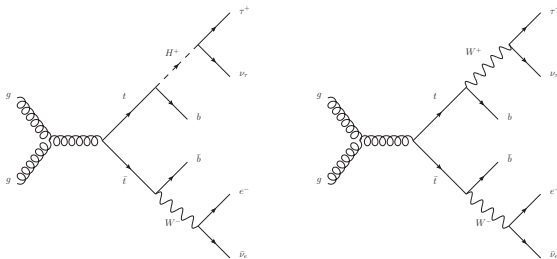
$$\mathcal{L} = \frac{g}{2\sqrt{2}M_W} \{ V_{tb}H^+ [\bar{u}_t (A(1 + \gamma_5) + B(1 - \gamma_5)) u_b] + CH^+ [\bar{u}_{\nu_l}(1 - \gamma_5)u_l] \}$$

Where  $A = m_t \cot \beta$ ,  $B = m_b \tan \beta$  and  $C = m_\tau \tan \beta$ . Note that the  $H^+$  ( $W^+$ ) coupling to leptons is right-handed (resp. left-handed).

The branching fractions involved are  $\mathcal{B}(H^+ \rightarrow \tau^+\nu_\tau) \simeq 1$  and  $\mathcal{B}(t \rightarrow bH^+)$  is obtained using FeynHiggs (Heinemeyer, Hollik and Weiglein) as a function of  $\tan \beta$  (see arXiv:0907.1498)



For this study,  $t\bar{t}$  and single top events are generated using Pythia 6.4 - Tauola. The decay chain of the top quark is  $t(\bar{t}) \rightarrow H^\pm b(\bar{b}) \rightarrow \tau^\pm \nu_\tau (\bar{\nu}_\tau) b(\bar{b})$ , where the  $\tau$  is left to decay hadronically in the  $\tau \rightarrow \rho \nu_\tau$  channel and the  $\rho$  meson decays via  $\rho^\pm \rightarrow \pi^\pm \pi^0$ . The event topologies of the signal and SM irreducible background for the  $t\bar{t}$  channel are described in the following diagrams.



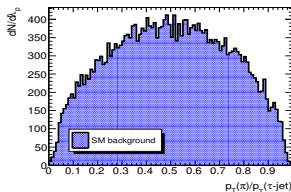
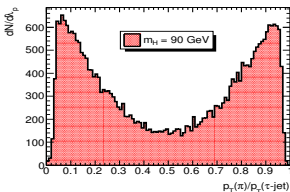
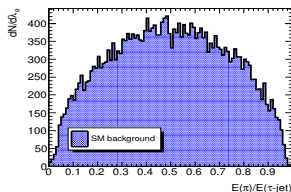
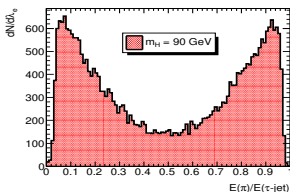
- $|\eta_l| < 2.5; \quad l = e, \mu.$
- $|\eta_{b,\bar{b}}| < 2.5.$
- $p_{T,l} > 20 \text{ GeV}.$
- $p_{T,b,\bar{b}} > 20 \text{ GeV}.$
- $p_{T,\rho} > 10 \text{ GeV}.$

- Helicity angle  $\psi$  introduced by Eriksson, Ingelman, Rathsmann, Stal [JHEP 801 (2008) 024]
- Energy and  $p_T$  of  $b$ -jets in  $t \rightarrow Wb$  and  $t \rightarrow Hb$ .
- Energy and  $p_T$  of  $\tau$ -jets in  $H^+, W^+ \rightarrow \tau \nu_\tau$ .
- Fractional energy and  $p_T$  of single charged prong in  $\tau$  decays.

Update of analysis by Hesselbach, Moretti, Rathsmann, Sopczak [EPJC 83 (2008) 311]

The  $\tau$  leptons coupling to  $H^\pm$  are right-handed, whereas those coupling to SM  $W^\pm$  bosons are left-handed. This leads to different angular distributions of the  $\tau$  decay products depending on the ratios  $E(\pi)/E(\rho)$  and  $p_T(\pi)/p_T(\rho)$  (Hagiwara, Martin, Roy, Zeppenfeld).

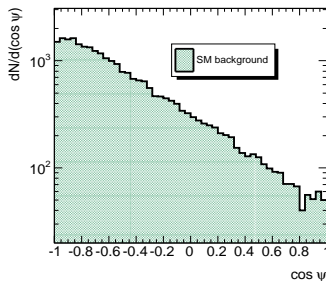
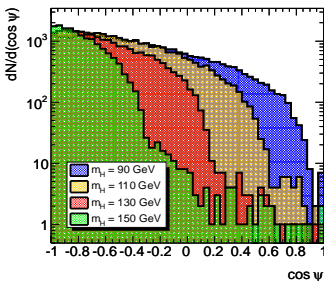
The distributions for these variables on the signal and background processes are shown below.



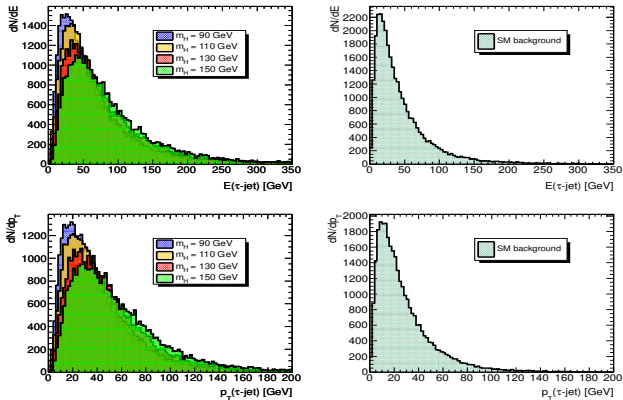
Another effect of the R-polarisation of the  $\tau$  can be seen on the distributions of the angle between the top quark and the  $\rho$  meson, in the reference frame where the  $W$  is at rest. The helicity angle  $\psi$  is defined as

$$\cos \psi = - \frac{\vec{p}_t \cdot \vec{p}_\rho}{|\vec{p}_t| |\vec{p}_\rho|} \bigg|_{\vec{p}_W=0} \simeq \frac{2m_{\rho b}^2}{m_t^2 - m_W^2} - 1$$

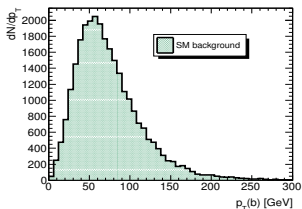
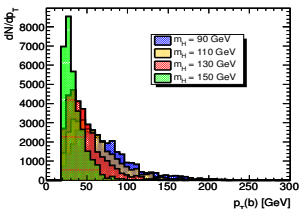
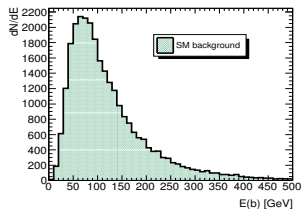
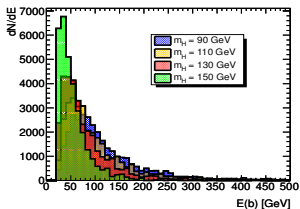
The distributions for  $\cos \psi$  for different  $H^+$  masses and for the SM background are shown below.



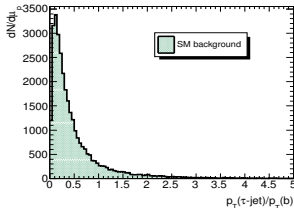
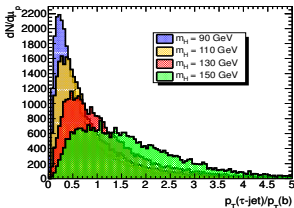
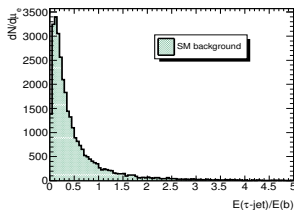
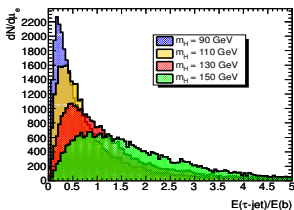
Since we consider the mass of the charged Higgs to be larger than  $m_W$ , the decay products of the  $\tau$  are expected to be harder in the energy and  $p_T$  spectra. The distributions of the  $\tau$  - jet energy and transverse momentum are shown below for different masses of  $H^\pm$  and for the SM background.



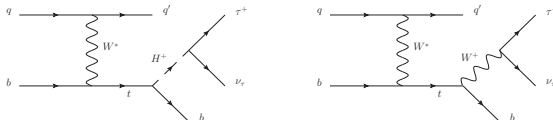
As the charged Higgs mass increases, we can see a decrease in the energy and  $p_T$  of the  $b$ -jet coming from the  $H^+$  production vertex (this jet can be identified using charge and angular correlations between the jet and the lepton from W). The distributions are shown below



Therefore, a good discriminating variable would be the ratio between the  $\tau$  energy or  $p_T$  and the  $b$  – jet energy or  $p_T$ . The distributions are shown below.



The single top t-channel diagrams are generated too.



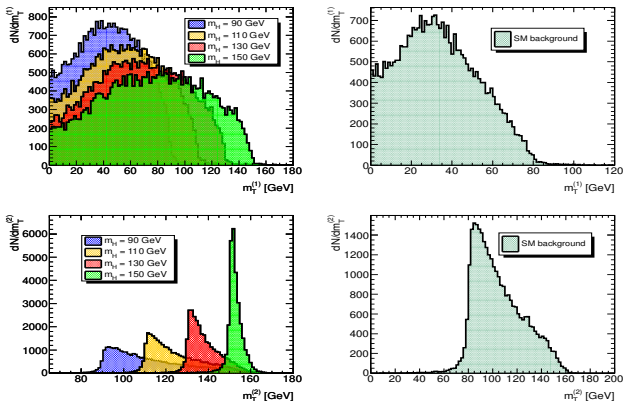
The advantage of this channel is that it allows for a measurement of the  $H^+$  mass as all the missing  $E_T$  comes from just one neutrino. The usual transverse mass, defined as in the  $W$  mass measurement is

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

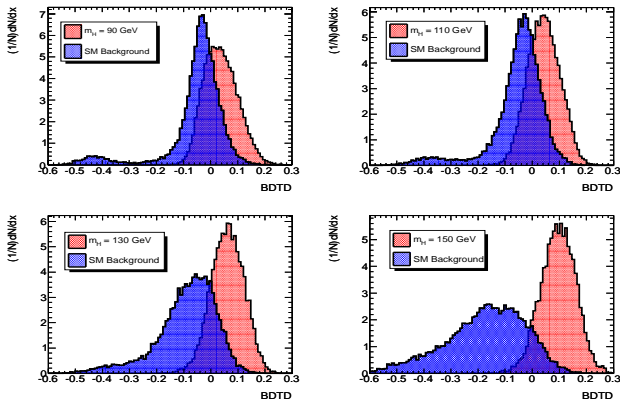
Where  $\Delta\phi$  is the angle between the  $\tau$  - jet and the reconstructed missing  $E_T$ . This variable provides a good discrimination between signal and background, but it doesn't allow us to measure the mass. To avoid this, we define the transverse mass as (Gross, Vitells [arXiv:0907.5367])

$$(m_T^H)^2 = \left( \sqrt{m_t^2 + (\vec{p}_T^\rho + \vec{p}_T^b + \vec{p}_T^{miss})^2} - p_T^b \right)^2 - (\vec{p}_T^\rho + \vec{p}_T^{miss})^2$$

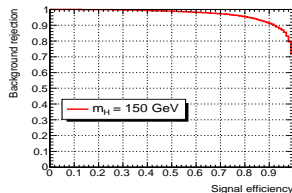
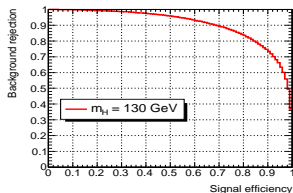
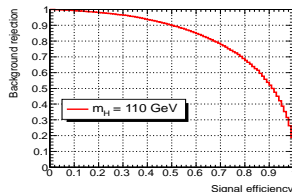
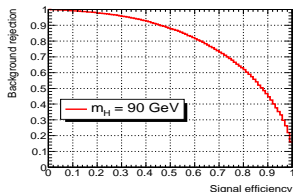
The distributions for the two transverse masses defined above are shown in the following plots for the signal and background processes.



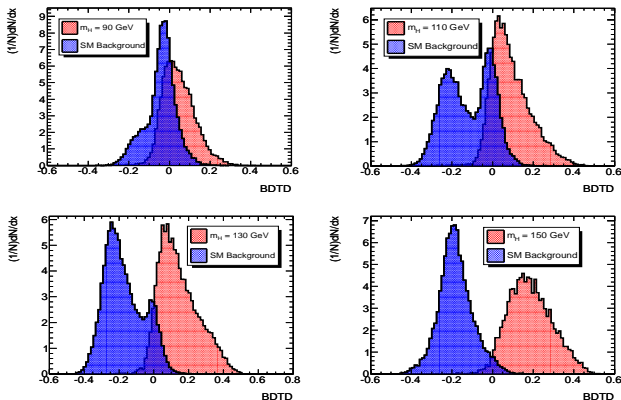
For the  $t\bar{t}$  channel, we use all those variables described above (except the transverse masses) to train a Decorrelated Boosted Decision Tree (BDTD) using TMVA. The results for the BDTD response functions for each  $m_H$  studied are shown below.



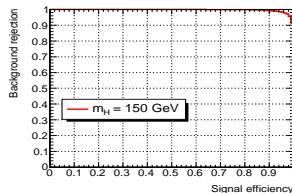
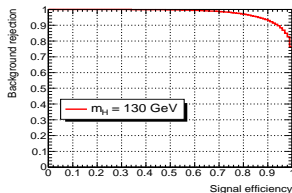
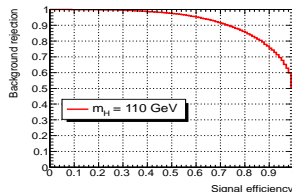
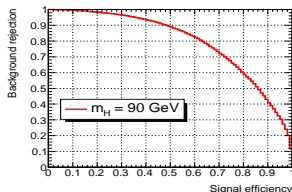
The ROC curves (Signal efficiency vs. Background rejection) for the  $t\bar{t}$  channel are shown in the following plots.



For the single top channel, we use all the variables (including the two definitions of the transverse mass) to train a Decorrelated Boosted Decision Tree (BDTD) using TMVA. The results for the BDTD response functions for each  $m_H$  studied are shown below.



The ROC curves (Signal efficiency vs. Background rejection) for the single Top channel are shown in the following plots.



- TMVA results show that a big significance wrt irreducible background can be achieved. Considering  $\tan \beta \simeq 10$  and  $m_H = 90$  GeV, the significance can be estimated to be  $S \sim 30(25)$  for the  $t\bar{t}$  and the single top channels, respectively.
- This estimated significance will reduce when taking into account the non- $t\bar{t}$  SM background (mainly  $W/Z$  +jets and di-boson production). It has been shown that these backgrounds can be efficiently separated from the SM  $t\bar{t}$  signal.
- As seen before, the separation achieved increases as  $m_H$  grows . However, as seen on slide 1, the branching fraction  $\mathfrak{B}(t \rightarrow H^+ b)$  decreases as  $m_H$  grows, and both effects somehow compensates.