Improved sensitivity for Charged Higgs searches in Top quark decays using τ polarisation and Multivariate Analysis

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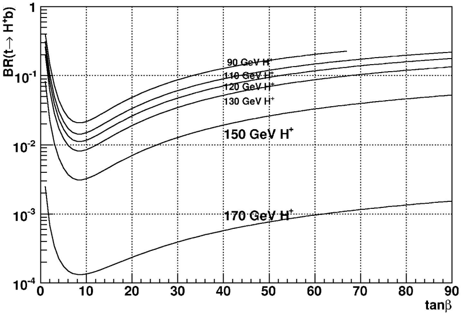
Theoretical background

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

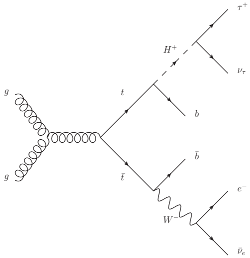
$$\mathcal{L} = \frac{g}{2\sqrt{2}M_W}\left\{V_{tb}H^+\left[\bar{u}_t\left(A(1+\gamma_5)+B(1-\gamma_5)\right)u_b\right]+CH^+\left[\bar{u}_{\nu_l}(1-\gamma_5)u_l\right]\right\}$$

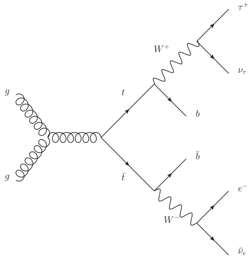
Where $A = m_t \cot\beta$, $B = m_b \tan\beta$ and $C = m_\tau \tan\beta$. Note that the coupling to leptons is right-handed, in opposition to SM.

The branching fractions involved are $\mathcal{B}(H^+ \to \tau^+\nu_\tau) \simeq 1$ for the chosen parameter values and $\mathcal{B}(t \to bH^+)$ is shown in the following figure as a function of $\tan\beta$ (arXiv:0907.1498)



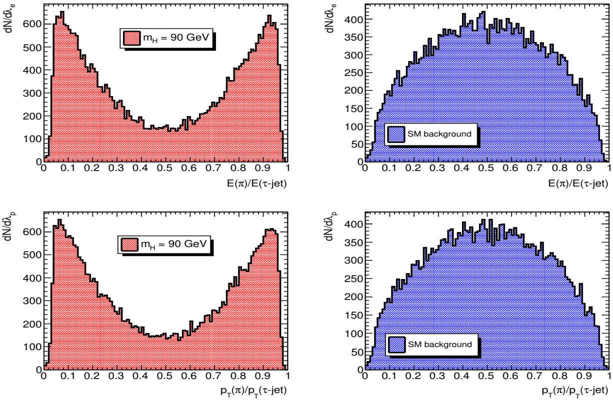
For this study, ttbar and single top events are generated using Pythia 6.4. The decay chain of the top quark is $t(\bar{t}) \rightarrow H^{\pm}b(\bar{b}) \rightarrow \tau^{\pm}\nu_{\tau}(\bar{\nu}_{\tau})b(\bar{b})$, where the τ is left to decay hadronically in the $\tau \rightarrow \rho\nu_{\tau}$ channel and the ρ 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.





Tau polarisation effects

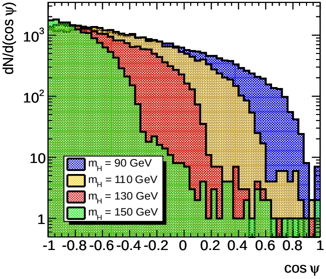
The τ leptons coupling to $H^{\pm}$ are right-handed, whereas those coupling to SM $W^{\pm}$ bosons are left-handed. This leads to different angular distributions of the τ decay products depending on the ratios $E(\pi)/E(\rho)$ and $p_T(\pi)/p_T(\rho)$. The distributions for this variables on the signal and background processes are shown below.

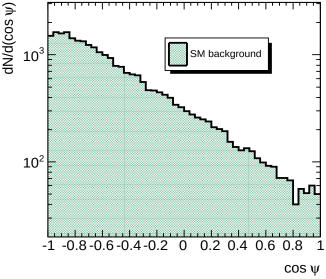


Another effect of the R-polarisation of the τ can be seen on the distributions of the angle between the top quark and the ρ meson, in the reference frame where the W is at rest. The helicity angle ψ is defined as

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

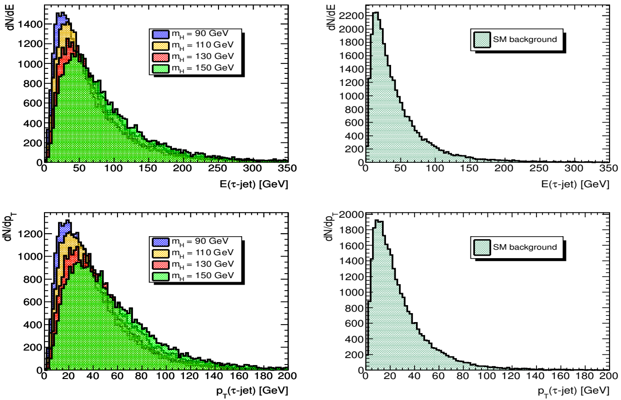
The distributions for $\cos\psi$ for different H^+ masses and for the SM background are shown below.



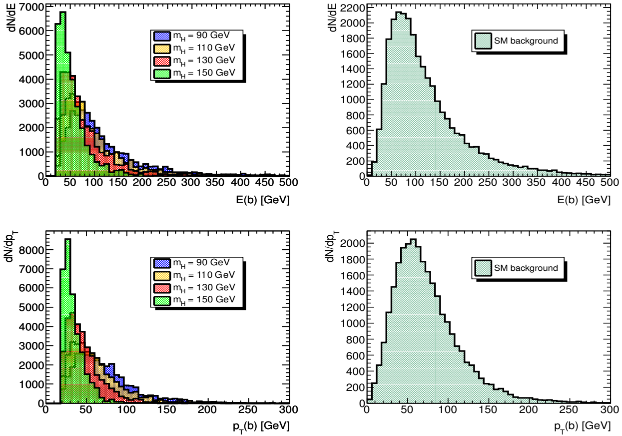


Kinematical effects ($m_t > m_H > m_W$): τ-jet

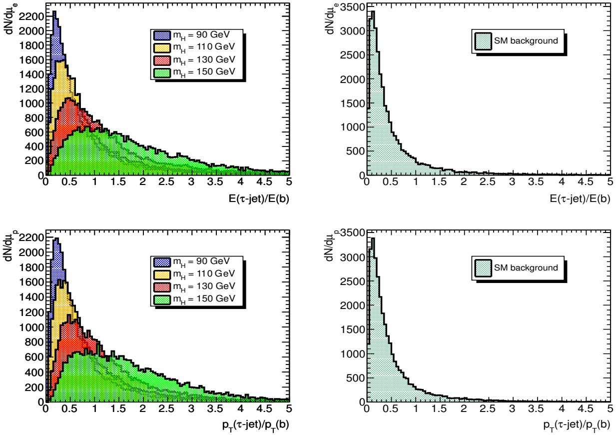
In the most favorable case, the mass of the charged Higgs is expected to be larger than m_W, the decay products of the τ are then expected to be harder in the energy and p_T spectra. The distributions of the $\tau - jet$ energy and transverse momentum are shown below for different masses of $H^{\pm}$ and for the SM background.



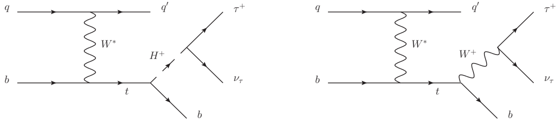
As the charged Higgs mass increases, we can see a decrease in the energy and p_T of the $b-jet$ coming from the H^+ production vertex (this jet can be identified using charge and angular correlations between the jet and the lepton from W). The distributions are shown below



Therefore, a good discriminating variable would be the ratio between the τ 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.



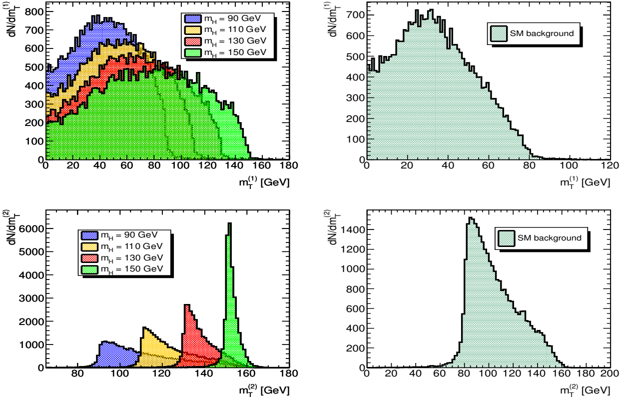
The advantage of this channel is that it allows for a measurement of the H^+ mass as all the missing E_T comes from just one neutrino. The usual transverse mass, defined as in the W mass measurement is

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

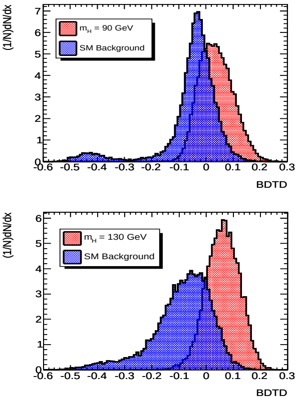
Where $\Delta\phi$ is the angle between the $\tau - jet$ and the reconstructed missing E_T. This variable provides a good discrimination between signal and background, but it doesn't allow us to measure the mass. To avoid this, we define the transverse mass as (arXiv:0907.5367)

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

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

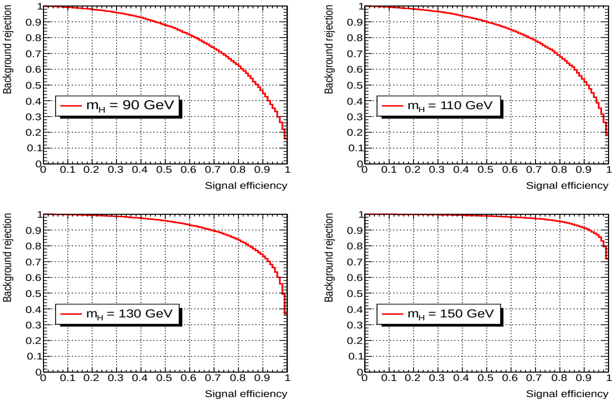


For the $t\bar{t}$ channel, we use all those variables described above (except the transverse masses) to train a Decorrelated Boosted Decision Tree (BDTD) using TMVA. The results for the BDTD response functions for each m_H studied are shown below.



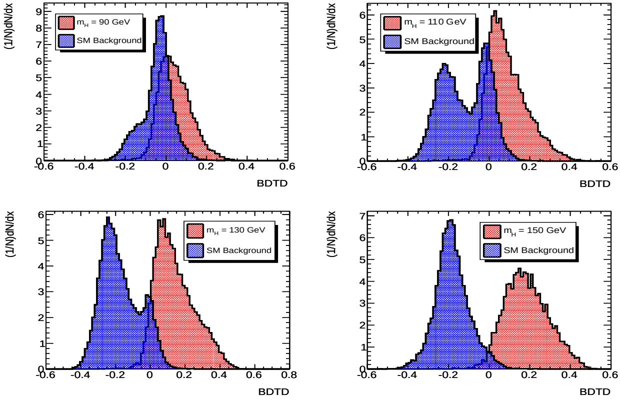
Top quark pair production. TMVA results

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



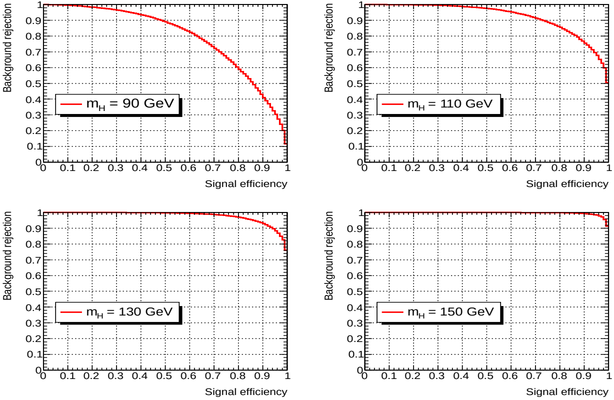
Single Top production. TMVA results

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.



Single Top production. TMVA results

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



Conclusions

- 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 in $S \sim 70$ for the ttbar channel.
- This estimated significance will reduce when taking into account the non-ttbar 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 $\mathfrak{B}(t \to H^+ b)$ decreases as m_H grows.