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

Javier Llorente

Universidad Autónoma de Madrid

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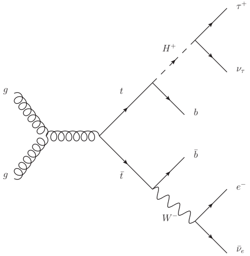
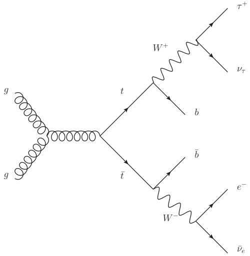
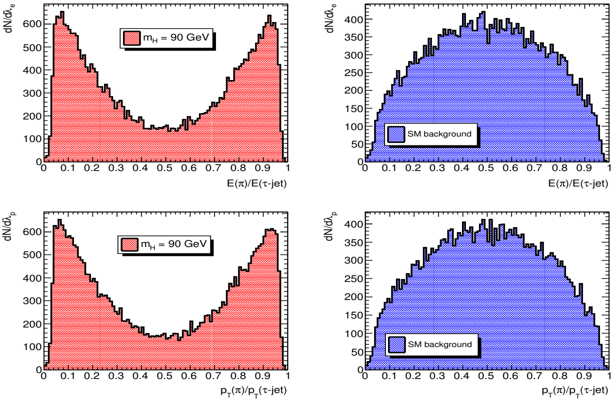
For this study, ttbar and single top events are generated using Pythia 6.4. The decay chain of the top quark is $t(\bar{t}) \to H^{\pm} b(\bar{b}) \to \tau^{\pm}\nu_{\tau}(\bar{\nu}_{\tau}) b(\bar{b})$, where the τ is left to decay hadronically in the $\tau \to \rho\nu_{\tau}$ channel and the ρ meson decays via $\rho^{\pm} \to \pi^{\pm}\pi^{0}$. 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

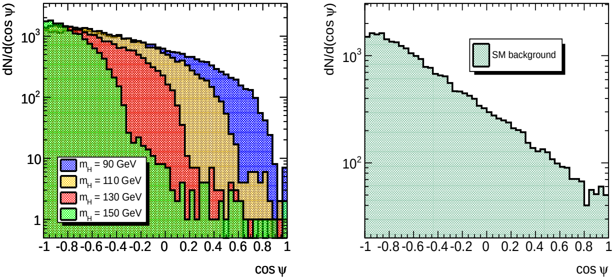
The τ leptons coupling to $H^{\pm}$ are right-handed, whereas those coupling to SM $W^{\pm}$ bosons are left-handed. This leads to different angular distributions of the τ decay products depending on the ratios $E(\pi)/E(\rho)$ and $p_T(\pi)/p_T(\rho)$. The distributions for this variables on the signal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

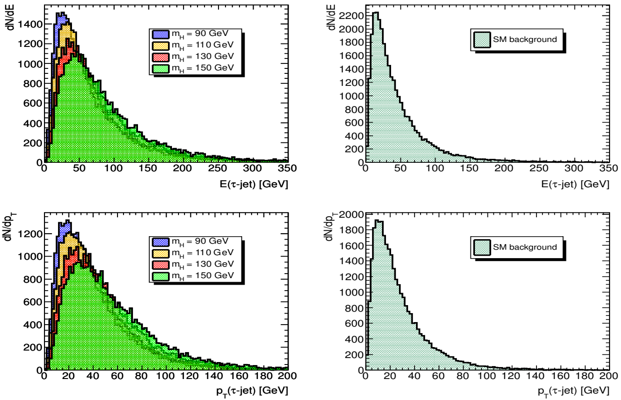
$$\cos\psi = -\left.\frac{\vec{p}_t \cdot \vec{p}_\rho}{|\vec{p}_t||\vec{p}_\rho|}\right|_{\vec{p}_W=0} \simeq \frac{2m_{\rho b}^2}{m_t^2 - m_W^2} - 1$$

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



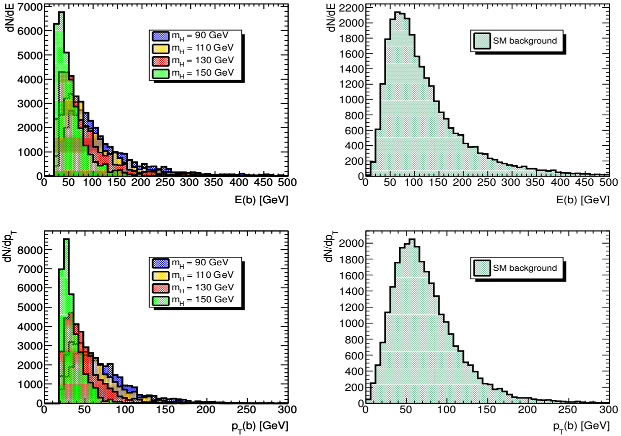
Kinematical effects ($m_t > m_H > m_W$)

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.



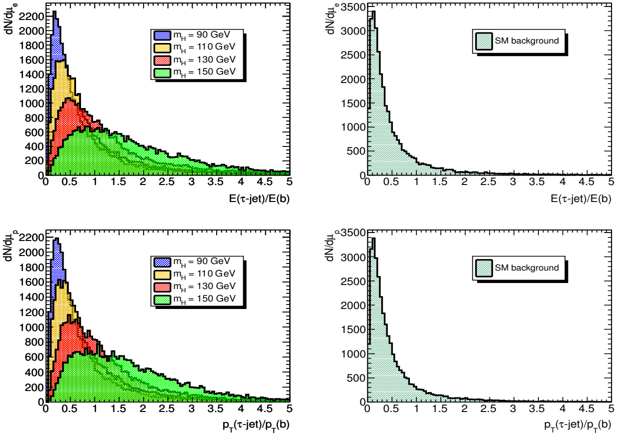
Kinematical effects ($m_t > m_H > m_W$)

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

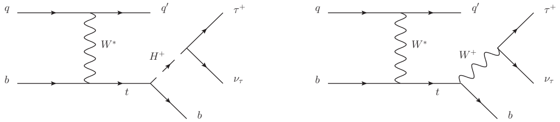


Kinematical effects ($m_t > m_H > m_W$)

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.



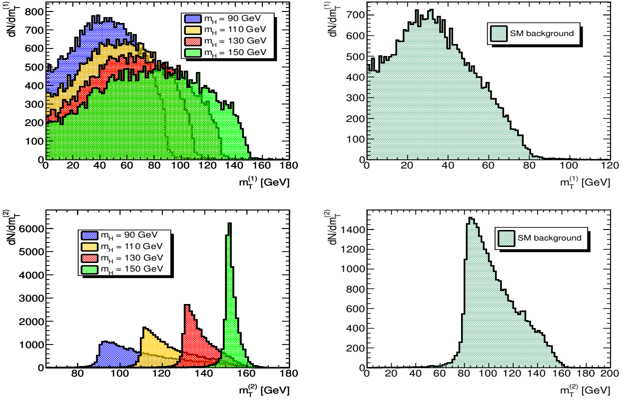
The advantage of this channel is that it allows for a measurement of the H^+ mass as all the missing E_T comes from the same branch, whereas in the $t\bar{t}$ channel, we had another neutrino from the $W \to l\nu_l$ decay. The usual transverse mass, defined as in the W mass measurement is

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

Where $\Delta\phi$ is the angle between the $\tau - jet$ and the reconstructed missing E_T. As we see, this variable provides a good discrimination between signal and background process, but it doesn't allow us to measure the actual mass of the charged Higgs. To avoid this, we define the transverse mass as [5]

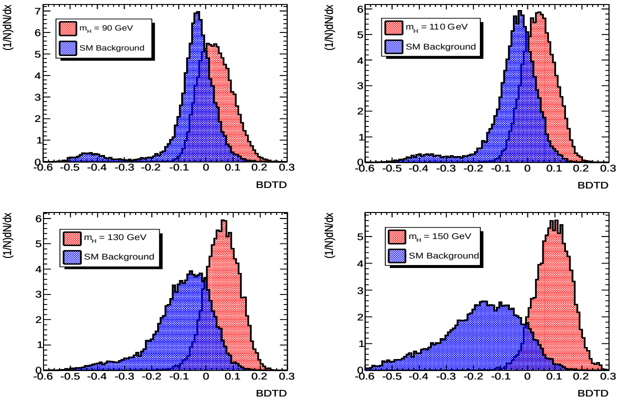
$$(m_T^H)^2 = \left(\sqrt{m_t^2 + (\vec{p}_T^\rho + \vec{p}_T^b + \vec{p}_T^{miss})^2} - p_T^b\right)^2 - (\vec{p}_T^\rho + \vec{p}_T^{miss})^2$$

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

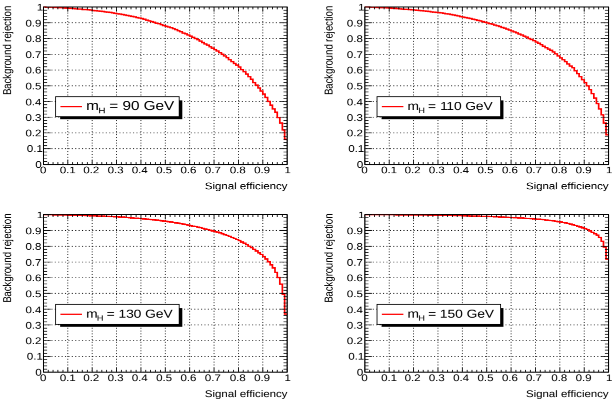


Top quark pair production. TMVA results

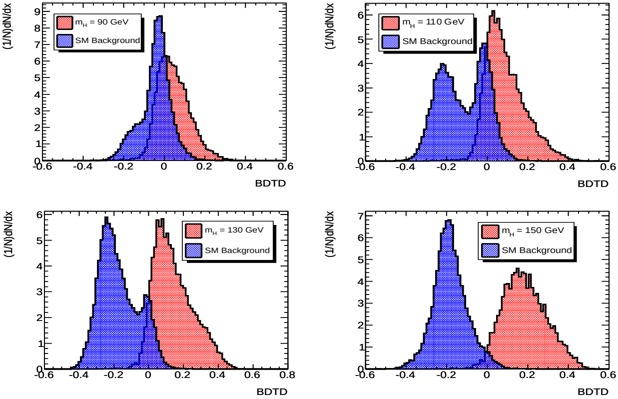
For the $t\bar{t}$ channel, we use all those variables described above (except the transverse masses) to train a Decorrelated Boosted Decision Tree (BDTD) using TMVA. The results for the BDTD response functions for each m_H studied are shown below.



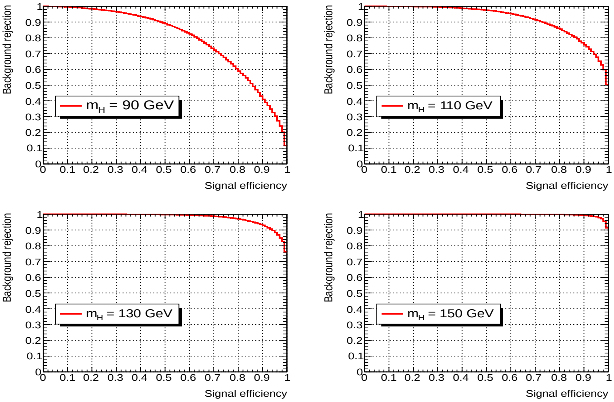
The ROC curves (Signal efficiency vs. Background rejection) for the $t\bar{t}$ channel are shown in the following plots.



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.

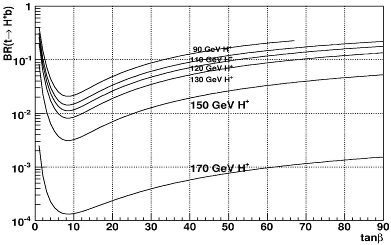


The ROC curves (Signal efficiency vs. Background rejection) for the single Top channel are shown in the following plots.



Conclusions

- TMVA results show that a big significance wrt ireducible 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 it is seen in the following plot, the branching fraction $\mathfrak{B}(t \to H^+ b)$ decreases as m_H grows.



References

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

[2] G. Aad et al. [The ATLAS Collaboration], [arXiv:0901.0512 (hep-ex)].

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

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

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