The Left-Right asymmetry of top quarks in associated top–charged Higgs bosons at the LHC as a probe of the tanβ parameter

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A widely studied extension of the Standard Model (SM) of the electroweak interactions is a two–Higgs doublet model (2HDM) in which two SU(2) doublets of complex scalar fields are introduced to break the electroweak symmetry. Such an extension of the Higgs sector is, for instance, necessary in the Minimal Supersymmetric extension of the Standard Model (MSSM) [1], which is one of the most attractive and investigated beyond–the–SM scenarios. These models lead to the existence of five scalar particles, two CP–even h, H bosons, a CP–odd or pseudoscalar A boson and two charged $H^\pm$ particles. Besides the four masses, two parameters are needed to describe the Higgs sector: a mixing angle α in the CP–even Higgs sector and the ratio $\tan\beta$ of the vacuum expectation values of the two Higgs fields. While these parameters are essentially free in a general 2HDM extension, they are related in the supersymmetric extension and only two of them are independent; these basic parameters may be taken to be the charged Higgs mass $M_{H^\pm}$ and $\tan\beta$. The measurement of these parameters are of great importance to identify the underlying model and to determine its basic characteristics.

While the masses of the Higgs particles can be measured, once they have been produced in a given process, from either the invariant mass of their decay products or anothers kinematic distributions in the case where some of these daughter particles are invisible, the parameter $\tan\beta$ can be only determined indirectly.

We propose to measure the parameter $\tan\beta$ form the left–right asymmetry that one can construct from the longitudinal polarization of the top quarks that are produced in association with the charged Higgs bosons (the latter decaying into the cleaner and detectable $\tau\nu$ final states, $H^\pm \to \tau^\pm\nu$) [2]. This polarization asymmetry is defined as the difference of cross sections for the production of left–handed and right–handed top quarks divided by their sum

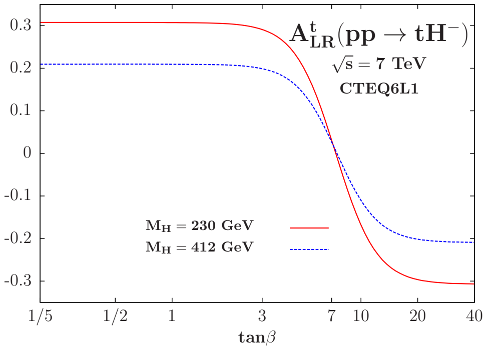

Figure 1. A_{LR} asymmetry at leading order in type II 2HDMs as a function of $\tan\beta$ in two benchmark scenarios with $M_{H^\pm}$ =230 and 412 GeV.

$$A^t_{LR} = \frac{\sigma(bg \to H^- t_L) - \sigma(bg \to H^- t_R)}{\sigma(bg \to H^- t_L) + \sigma(bg \to H^- t_R)} \equiv \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} \quad (1)$$

Being a ratio of observables of similar nature, the asymmetry is significantly less affected by the scale and PDF uncertainties compared to the cross section. One is then mainly left only with the experimental uncertainties in the determination of the cross sections and the measurement of the polarization of the top quarks.

In Fig. 1 is shown the left–right asymmetry A^t_{LR} at the LHC as a function of $\tan\beta$ for two values $M_{H^\pm}$ =230 and 412 GeV in two 2HDMs scenarios of type II [2]. As can be seen from Fig. 1 for a given $M_{H^\pm}$ value, the asymmetry allows to discriminates between the large and small $\tan\beta$ regions in a type II 2HDM.

The asymmetry A^t_{LR} has been evaluated only at the tree–level as the next–to–leading order (NLO) QCD corrections are not available. It is now customary to estimate the effects of these yet uncalculated higher order QCD contributions on a given observable at hadron colliders from the variation of the observable with respect to the renormalization μ_R and factorization μ_F scales at which the process is evaluated. Starting from a median scale μ_0, which in our case is taken to be $\mu_R = \mu_F = \mu_0 = \frac{1}{6}(M_{H^\pm} + m_t)$, the current convention is to vary these two scales within the range $\mu_0/\kappa \leq \mu_R, \mu_F \leq \kappa\mu_0$ with the constant factor chosen to be $\kappa = 2, 3$ or 4 depending on the

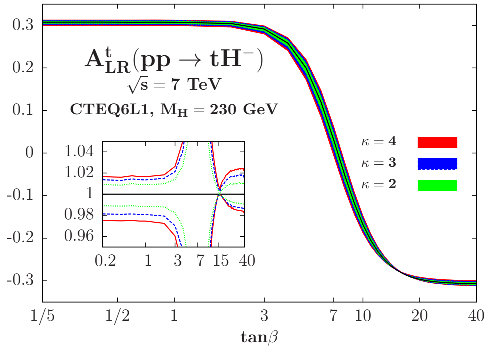

Figure 2. The scale variation of the asymmetry A^t_{LR} at leading order at the LHC with $\sqrt{s} = 7$ TeV in type II 2HDMs as a function of $\tan\beta$ for $M_{H^\pm} = 230$ GeV. In the inserts, shown are the variations with respect to the central value.

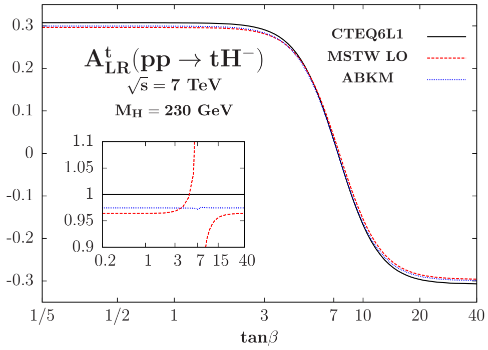

Figure 3. The PDF dependence of the asymmetry A^t_{LR} at leading order at the LHC with $\sqrt{s} = 7$ TeV in type II 2HDMs as a function of $\tan\beta$ for $M_{H^\pm} = 230$ GeV. In the inserts, shown are the variations with respect to the central value.

process.

In Fig. 2 is shown the variation of the polarization asymmetry with the scales for the choices $\kappa = 2, 3$ and 4 and one can see that this variation is very mild: at low and high $\tan\beta$ values, it is at most at the level of $\approx 2\%$ even for the extreme choice $\kappa = 4$. At moderate values $\tan\beta \approx 7$, for which the asymmetry vanishes, the relative variation is of course much larger as shown in the inserts of Fig. 2 (where the deviation from the asymmetry value when the central scale is adopted), but the impact is similar and thus small in absolute terms.

Another source of uncertainties stems from the presently not satisfactory determination of the gluon and bottom quark PDFs. One way to estimate this type of uncertainty would be to evaluate the asymmetry using other PDF parameterizations. In Fig. 3, the asymmetry is shown at the LHC with $\sqrt{s} = 7$ TeV and $M_{H^\pm} = 230$ GeV for different PDF sets. As can be seen, the difference between the various predictions is rather small, being less than a few percent at low and high $\tan\beta$ values at which the asymmetry is significant. This has to be contrasted with the total cross section for which the PDF uncertainties are expected to be much larger [3].

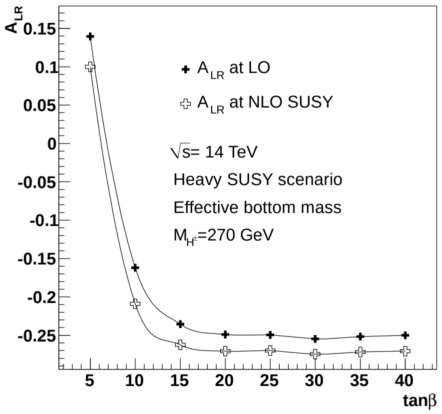

Figure 4. A^t_{LR} asymmetry at leading order and including the NLO electroweak corrections at the LHC with $\sqrt{s} = 14$ TeV in the MSSM with a heavy superparticle spectrum as a function of $\tan\beta$ in the case with $M_{H^\pm} = 270$.

A final remark is to be made on the non–standard radiative corrections in supersymmetric scenarios. In the MSSM, the process $gb \to H^- t$ is affected by radiative corrections which involve the supersymmetric particle spectrum. In Fig. 4, we display the impact of NLO SUSY radiative corrections on left–right asymmetry in the MSSM in the scenario presented in Ref. [2] where a heavy superparticle spectrum is assumed and the charged Higgs mass fixed to $M_{H^\pm} = 270$ GeV.

As can be seen these effects can be large. For $\tan\beta > 15$ where the asymmetry dependence on $\tan\beta$ is almost flat, there is a $\approx 10\%$ effect on the loop corrections, making the asymmetry sensitive to the quantum contributions of the superparticle spectrum.

In conclusion we point out that, in associated production of charged Higgs bosons and top quarks at the LHC, one can construct a left–right asymmetry by identifying the polarization of the top quarks. This asymmetry is rather stable against the variation of the QCD scales and the choice of parton distribution functions but is still sensitive to quantum effects in new physics scenarios such as Supersymmetry. If measured with some accuracy, the top quark polarization asymmetry in this process allows a very nice determination of the parameter $\tan\beta$.

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