Abstract

In this dissertation, the Minimal Supersymmetric Standard Model (MSSM) is studied as a low-energy theory stemming from the $SU(5)$ Grand Unified Theory (GUT). The well-known gauge coupling unification in the MSSM is considered to be one of the main virtues of the model. Similarly, Yukawa couplings of the bottom quark and tau lepton become relatively close to each other at the GUT scale $M_{\rm GUT} \simeq 2 \times 10^{16}\,\text{GeV}$. However, it is not the case for the first- and second-generation Yukawa couplings, unless large threshold corrections arise at the scale $\mu_{\rm sp}$ at which the superpartners are being decoupled. Here, we investigate a possibility of satisfying the minimal $SU(5)$ boundary condition $\mathbf{Y}^d = \mathbf{Y}^{eT}$ for the full 3×3 down-quark and lepton Yukawa matrices at the GUT scale within the R-parity conserving MSSM.

We give numerical evidence in favour of the statement:

There exist regions in the parameter space of the R-parity conserving MSSM for which the unification of the down-quark and lepton Yukawa matrices takes place, while the predicted values of flavour, electroweak and other collider observables are consistent with experimental constraints.

Furthermore, we find evidence that the bottom-tau and strange-muon Yukawa unification is possible with a stable MSSM vacuum in the standard form, where only the neutral Higgs fields acquire non-vanishing vacuum expectation values. However, if the equality of the electron and down-quark Yukawa couplings at $M_{\rm GUT}$ is demanded, only such cases remain, for which the standard MSSM vacuum is metastable, though sufficiently long-lived.

We investigate two separate scenarios of the soft supersymmetry breaking terms at $M_{\rm GUT}$. In the first one, it is assumed that the soft terms are non-universal but flavour-diagonal in the super-CKM basis. In such a case, the trilinear Higgs-squark-squark A-terms can generate large threshold corrections to the Yukawa matrix $\mathbf{Y}^d$ at the superpartner decoupling scale $\mu_{\rm sp}$, while no significant new contributions to the Flavour Changing Neutral Current processes are generated. In effect, the $SU(5)$ boundary condition $\mathbf{Y}^d = \mathbf{Y}^{eT}$ at the GUT scale can be satisfied. However, the large trilinear terms make the usual Higgs vacuum metastable (though sufficiently long-lived). We broaden the previous studies of such a scenario by including results from the first LHC phase, notably the measurement of the Higgs particle mass, as well as a quantitative investigation of the relevant flavour observables.

In the second scenario, we consider non-vanishing flavour off-diagonal entries in the soft SUSY-breaking mass matrices. As we aim to alleviate the metastability problem, the diagonal A-terms are assumed to be proportional to the respective Yukawa couplings. We show that a non-trivial flavour structure of the soft SUSY-breaking sector can allow a precise bottom-tau and strange-muon Yukawa coupling unification, while satisfying all phenomenological constraints.