MEETING HIGGS AND ELECTROWEAK PRECISION OBSERVABLES WITH R-SYMMETRIC SUSY*

Philip Diessner[a], Wojciech Kotlarski[a,b]

[a]Institute of Nuclear and Particle Physics, TU Dresden
Zellescher Weg 19, 01069 Dresden, Germany
[b]Faculty of Physics, University of Warsaw
Pasteura 5, 02-093 Warsaw, Poland

(Received October 25, 2015)

We briefly review results of a recent calculation of the leading two-loop corrections to the Higgs boson mass in the Minimal R-symmetric Supersymmetric Standard Model.

DOI:10.5506/APhysPolB.46.2179
PACS numbers: 12.60.Jv, 14.80.Ly

1. Introduction

The Standard Model of Particle Physics, despite its success at describing most of the available experimental data, cannot be the fundamental theory of Nature. Phenomena such as the existence of dark matter or the anomalous magnetic moment of the muon call for its extension. These questions could be addressed by supersymmetry, and for many the Minimal Supersymmetric Standard Model (MSSM) is the theory of choice. But despite a very successful Run 1, no sign of supersymmetry was found at the LHC. Therefore, one has to consider the possibility that low scale SUSY, if it is realized in Nature, might not be realized in the minimal way. This generated a lot of interest in both simple extensions of the MSSM, like the NMSSM, and more involved but arguably theoretically better motivated, like for example the Minimal R-symmetric Supersymmetric Standard Model (MRSSM). The latter one, proposed in Ref. [1] in the context of ameliorating the flavor problem of the MSSM, looks also very promising from the point of view of Higgs physics.

The Higgs sector of this model was worked out in Refs. [2, 3]. This included calculations of full one-loop and partial two-loop corrections to the mass spectrum. In this work, we summarize briefly results of the two-loop analysis.

* Presented by W. Kotlarski at the XXXIX International Conference of Theoretical Physics "Matter to the Deepest", Ustroń, Poland, September 13–18, 2015.

2. Model definition

A distinctive feature of the MRSSM is the presence of a global U(1) symmetry, called R-symmetry, under which Grassmann coordinates θ are charged. This implies that in an R-symmetric theory, different component fields of the corresponding superfield have different R-charges. Table I shows the field content of the MRSSM together with R-charge assignment. Since this assignment forbids the existence of MSSM-like $\mu \hat{H}_u \cdot \hat{H}_d$ term in the superpotential along with soft-breaking gaugino masses, the MSSM field content is extended by R-Higgs weak iso-doublets $\hat{R}_{u,d}$ and gauge-adjoint chiral superfields $\hat{S}$, $\hat{T}$ and $\hat{O}$ (respectively for U(1), SU(2) and SU(3) gauge groups). The superpotential for the model is then given by

$$\begin{aligned} W \;=\; & \mu_d \hat{R}_d \cdot \hat{H}_d + \mu_u \hat{R}_u \cdot \hat{H}_u \\ & + \Lambda_d \hat{R}_d \cdot \hat{T} \hat{H}_d + \Lambda_u \hat{R}_u \cdot \hat{T} \hat{H}_u + \lambda_d \hat{S} \hat{R}_d \cdot \hat{H}_d + \lambda_u \hat{S} \hat{R}_u \cdot \hat{H}_u \\ & - Y_d \hat{d} \hat{q} \cdot \hat{H}_d - Y_e \hat{e} \hat{l} \cdot \hat{H}_d + Y_u \hat{u} \hat{q} \cdot \hat{H}_u \,. \end{aligned} \tag{1}$$

Bilinear terms are the replacement for the forbidden $\mu \hat{H}_u \cdot \hat{H}_d$ term. The Λ, λ-terms are similar to the usual Yukawa terms, where the $\hat{R}$-Higgs and $\hat{S}$ or $\hat{T}$ play the role of the quark/lepton doublets and singlets. Additionally, one is allowed to add Dirac gaugino mass terms pairing $\tilde{B}$, $\tilde{W}^a$ and $\tilde{g}^a$ with fermionic components of $\hat{S}$, $\hat{T}$ and $\hat{O}$.

TABLE I

The R-charges of the superfields and the corresponding bosonic and fermionic components.

Field	Superfield		Boson		Fermion	
Gauge vector	$\hat{g}, \hat{W}, \hat{B}$	0	g, W, B	0	$\tilde{g}, \tilde{W} \tilde{B}$	+1
Matter	$\hat{l}, \hat{e}$	+1	$\tilde{l}, \tilde{e}^*_R$	+1	l, e^*_R	0
	$\hat{q}, \hat{d}, \hat{u}$	+1	$\tilde{q}, \tilde{d}^*_R, \tilde{u}^*_R$	+1	q, d^*_R, u^*_R	0
H-Higgs	$\hat{H}_{d,u}$	0	$H_{d,u}$	0	$\tilde{H}_{d,u}$	−1
R-Higgs	$\hat{R}_{d,u}$	+2	$R_{d,u}$	+2	$\tilde{R}_{d,u}$	+1
Adjoint chiral	$\hat{\mathcal{O}}, \hat{T}, \hat{S}$	0	O, T, S	0	$\tilde{O}, \tilde{T}, \tilde{S}$	−1

In the scalar sector, after the electroweak symmetry breaking, (neutral) scalar components of $\hat{H}_d, \hat{H}_u, \hat{S}$ and $\hat{T}$ acquire vevs, which are parametrized as

$$\begin{aligned} H_d^0 &= \frac{1}{\sqrt{2}}(v_d + \phi_d + i\sigma_d)\,, \qquad H_u^0 = \frac{1}{\sqrt{2}}(v_u + \phi_u + i\sigma_u)\,, \\ T^0 &= \frac{1}{\sqrt{2}}(v_T + \phi_T + i\sigma_T)\,, \qquad S = \frac{1}{\sqrt{2}}(v_S + \phi_S + i\sigma_S)\,. \end{aligned}$$

CP-even components $\{\phi_d, \phi_u, \phi_S, \phi_T\}$ mix giving rise to 4 physical scalar Higgs bosons. For m_S and $m_T \gtrsim 1$ TeV, the lightest Higgs mass is always lower than in the MSSM due to the mixing, requiring large radiative corrections to reach the measured value.

In Ref. [2], it was shown that for values of Λ_u smaller than -1, it is possible to obtain a Higgs boson mass of around 125 GeV. This posed a question about the importance of higher order corrections, which we address in the next section.

3. Leading two-loop corrections to the lightest Higgs boson mass

Two-loop corrections to the Higgs boson mass in the MRSSM are interesting as it is the first time when they become sensitive to pure-QCD sector of the model, namely to sgluons and gluinos. The relevant contributions in the effective potential approximation are depicted in Fig. 1, with relevant vertices shown in Fig. 2. The corresponding analytic expresion reads

$$\begin{aligned} V_{\text{eff}}^{(2)} &= \frac{8g_3^2}{(16\pi^2)^2}\left(M_O^{\text{D}}\right)^2 \sum_{i=L,R} f_{SSS}\left(m^2_{\tilde{t}_i}, m^2_{\tilde{t}_i}, m^2_{O_S}\right) \\ &\quad + \frac{8g_3^2}{(16\pi^2)^2} \sum_{i=L,R} f_{FFS}\left(m^2_t, m^2_{\tilde{t}_i}, m^2_{\tilde{g}_{\text{D}}}\right) , \end{aligned} \tag{2}$$

where functions f are defined in Ref. [4]. The correction to the $\phi_u\phi_u$ element of the Higgs mass matrix is then given by[1]

$$\left[\Delta m^2_{H_1}\right]_{\phi_u\phi_u} = \left(\frac{\partial^2}{\partial v_u \partial v_u} - \frac{1}{v_u}\frac{\partial}{\partial v_u}\right) V_{\text{eff}}^{(2)} . \tag{3}$$

Its impact is shown in Fig. 3 for one of the benchmark points of Ref. [3]. One sees that without the sgluon contribution, the result is similar to the case in MSSM without stop mixing (as there is no stop mixing in the MRSSM). The sgluon contribution is always positive and apart from a region of parameter space where the gluino is light (below 1 TeV), the total contribution form sgluon and gluino drives Higgs mass upwards. The strong dependence of the sgluon contribution on the Dirac mass parameter M_{D}^O originates not only from the prefactor $(M_O^{\text{D}})^2$ in Eq. (2), but also from CP-event sgluon mass which grows with M_{D}^O as $m^2_{O_S} = 4(M_O^{\text{D}})^2 + m^2_O$.

[1] We emphasize that, while Eq. (2) is important for qualitative understanding of the two-loop MRSSM contributions, the full calculation was done using `SARAH`'s generated two-loop routines [5, 6]. Therefore, they include all contribution to the Higgs mass matrix (in the gauge-less limit and effective potential approximation), and not only to the $\phi_u\phi_u$ matrix element.

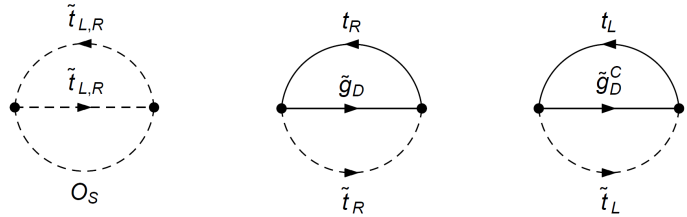

Fig. 1. Two-loop diagrams contributing to the Higgs boson mass via Eq. (2) that depend on the Dirac mass M_O^{D} and the soft sgluon mass m_O. We only draw diagrams involving top/stop; similar diagrams exist for all quark/squark flavors.

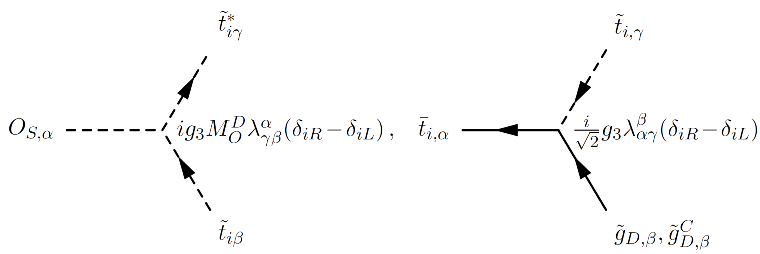

Fig. 2. Feynman rules needed to evaluate diagrams of Fig. 2. In the right diagram, the charge-conjugated gluino $\tilde{g}^C_{\mathrm{D},\beta}$ applies in the case of $i = L$, $\tilde{g}_{\mathrm{D},\beta}$ in the case of $i = R$.

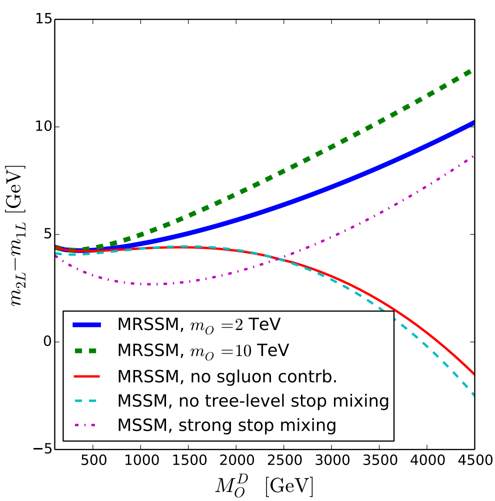

Fig. 3. Two-loop contributions to the SM-like Higgs boson mass depending on the gluino mass in the MRSSM for BMP1 of Ref. [3] for 2 different values of sgluon's soft-mass parameter m_O. Without the sgluon contribution, the result is similar to the result for analogous parameter point in the MSSM without stop mixing.

In total, two-loop corrections in the $\overline{\mathrm{DR}}$ scheme are usually positive and push the Higgs mass up by around +5 GeV as shown in the left panel of Fig. 4. Their inclusion allowed to modify the original benchmark points of Ref. [2], reducing the values of $|\Lambda_u|$ superpotential coupling. The right panel of Fig. 4 shows Higgs- and W-boson masses in the Λ_u–μ_u plane, where the star denotes the aforementioned benchmark point with and without two-loop corrections (black and white star, respectively). It should be stressed that an inclusion of these corrections pushes the benchmark point towards the region favored by the constraints from W-boson mass measurements (given by dashed contours), therefore reducing the tension between these two observables.

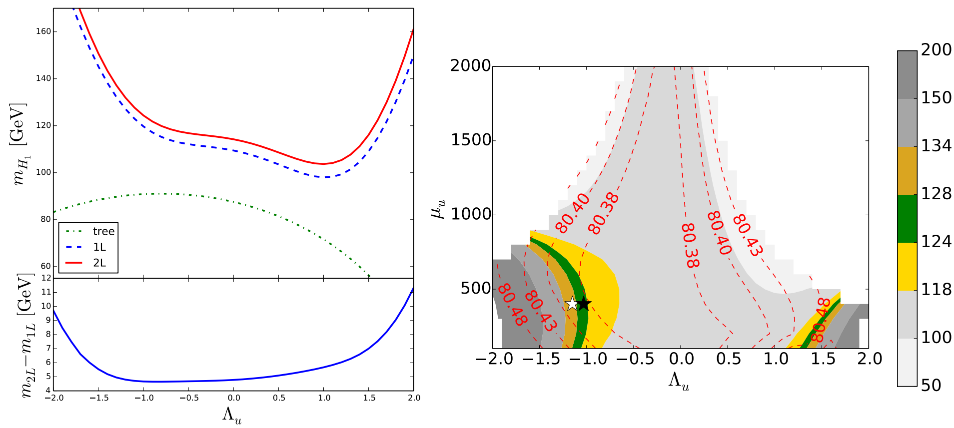

Fig. 4. Left figure shows a comparison of the dependence of lightest Higgs boson mass on the superpotential coupling Λ_u at tree, one- and two-loop levels. Right figure presents interdependence of Higgs- and W-masses. Dashed contour lines show W-mass predictions, while the color gradient shows Higgs masses (both in GeV). The white star corresponds to the original benchmark point of Ref. [2], the black one to the adopted point of Ref. [3].

4. Summary

In this note, we have reviewed recent calculation of leading two-loop corrections to the lightest Higgs boson mass in the Minimal R-symmetric Supersymmetric Standard Model. Their addition allows to reduce size of the superpotential coupling $|\Lambda_u|$ by around 10%, reducing the slight tension between predicted Higgs- and W-boson masses. It also showed the importance of the sgluon contribution, and its strong parametric dependence on Dirac gluino mass parameter M_O^{D}.

Work supported in part by the German DFG Research Training Group 1504 and the DFG grant STO 876/4-1, the Polish National Science Centre grants under OPUS-2012/05/B/ST2/03306 and the European Commission through the contract PITN-GA-2012-316704 (HIGGSTOOLS).

REFERENCES

[1] G.D. Kribs, E. Poppitz, N. Weiner, *Phys. Rev. D* **78**, 055010 (2008).

[2] P. Diessner, J. Kalinowski, W. Kotlarski, D. Stöckinger, *J. High Energy Phys.* **1412**, 124 (2014).

[3] P. Diessner, J. Kalinowski, W. Kotlarski, D. Stöckinger, *Adv. High Energy Phys.* **2015**, 760729 (2015).

[4] S.P. Martin, *Phys. Rev. D* **65**, 116003 (2002).

[5] M.D. Goodsell, K. Nickel, F. Staub, *Eur. Phys. J. C* **75**, 32 (2015).

[6] M. Goodsell, K. Nickel, F. Staub, *Eur. Phys. J. C* **75**, 290 (2015).