CONFRONTING THE COLOURED SECTOR OF THE MRSSM WITH LHC DATA*

Philip Diessner

Deutsches Elektronen-Synchrotron DESY
Notkestraße 85, 22607 Hamburg, Germany

Jan Kalinowski

Faculty of Physics, University of Warsaw
Pasteura 5, 02-093 Warszawa, Poland

Wojciech Kotlarski, Dominik Stöckinger

Institut für Kern- und Teilchenphysik, TU Dresden
Zellescher Weg 19, 01069 Dresden, Germany

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We review how the limits on squark masses coming from their direct searches at the Large Hadron Collider change in the non-minimal supersymmetric model. Particularly, we look at the well-motivated SUSY model with a continues R-symmetry — the so-called Minimal R-symmetric Supersymmetric Standard Model. We show that, in a scenario with degenerate squark masses and heavy gluino, the squark mass limit is $m_{\tilde{q}} > 1.7$ TeV — approximately 600 GeV lower than in the MSSM.

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1. Introduction

With the experimental collaborations progressing towards finishing the analysis of the full data set collected during Run 2 of the Large Hadron Collider (LHC), the available parameter space of supersymmetric (SUSY) models for strongly interacting particles is seemingly pushed into a few TeV range. While presented in a simplified scenarios, keeping in mind that limits in realistic models would be much weaker, this is still far from what was expected. After all, the hope was that SUSY would be discovered already at the very start of the LHC. Care should be taken though not to jump to

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conclusions prematurely. It should not be forgotten that all of the models analysed officially by the experimental collaborations are, after all, MSSM-inspired. It has been shown for example in [1] that a lot of those limits are therefore very MSSM-specific. This was one of the sources of interest in viable non-minimal supersymmetric models which we see for the last few years.

The Minimal R-symmetric Supersymmetric Standard Model (MRSSM) [2] is an example of such a model. Originally considered for its natural suppression of flavour-violating contributions [2, 3], turned out to have non-trivial and interesting phenomenology very different from the MSSM [4–8]. Nevertheless until recently there was no dedicated comparison of predictions for the strongly interacting sector with the LHC data. In this work we summarize the study of exclusion limits for squark and gluino production in the MRSSM from Ref. [9] where this has been addressed.

2. The MRSSM

Realisation of a phenomenologically viable model with an R-symmetry requires extension of the field content of the model compared to the MSSM. To form Dirac mass terms for gauginos, one adds chiral multiplets $\hat{O}, \hat{T}, \hat{S}$ in the adjoint representations of SM gauge groups. Meanwhile, a replacement for an MSSM μ-term requires adding two $\mathrm{SU}(2)_{\mathrm{L}}$ doublets of R-charge 2 Higgses — the so-called R-Higgses. The content of the model is summarized in Table I.

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	$\tilde{l}, \tilde{e}^*_{\mathrm{R}}$	+1	l, e^*_{R}	0
	$\hat{q}, \hat{d}, \hat{u}$	+1	$\tilde{q}, \tilde{d}^*_{\mathrm{R}}, \tilde{u}^*_{\mathrm{R}}$	+1	$q, d^*_{\mathrm{R}}, u^*_{\mathrm{R}}$	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	$\hat{O}, \hat{T}, \hat{S}$	0	O, T, S	0	$\tilde{O}, \tilde{T}, \tilde{S}$	−1

The mass spectrum of the SQCD sector is governed mostly by the soft-breaking Lagrangian

$$\begin{aligned}\mathcal{L}_{\mathrm{soft}} = &- \tfrac{1}{2}(m^2_{\tilde{q}_{\mathrm{L}}})_{ij}\tilde{q}^\dagger_{i\mathrm{L}}\tilde{q}_{j\mathrm{L}} - \tfrac{1}{2}(m^2_{\tilde{q}_{\mathrm{R}}})_{ij}\tilde{q}^\dagger_{i\mathrm{R}}\tilde{q}_{j\mathrm{R}} - m^2_O\,|O^a|^2 - m_{\tilde{g}}\bar{\tilde{g}}\tilde{g} \\ &+ m_{\tilde{g}}\left(\sqrt{2}D^aO^a + \mathrm{h.c.}\right),\end{aligned} \tag{1}$$

where D^α is the auxiliary field in $\mathrm{SU}(3)_\mathrm{C}$ sector. The structure of the model motives scenarios where gluino mass is heavy [10]. This also means that one of the components of the complex sgluon field, split by the D-term contribution from Eq. (1) into states of mass $m_{O_p} = m_O$ and $m_{O_s} = \sqrt{m_O^2 + 4m_{\tilde{g}}^2}$, is heavy. Remaining field O_p can be to a large extent studied in a model-independent way. All this motivates to considering scenarios, in which squarks are the lightest colour charged particles of the MRSSM.

At pp collider, squarks are produced at the leading order through diagrams in Fig. 1. Due to the R-charge conservation, only opposite chirality squarks are produced in the same-sign squark production. This has important phenomenological consequences. As the cross section for heavy squark-pair production is dominated by the last diagram in Fig. 1, the lack of some of the contributions significantly modifies the mass reach of the LHC. This is shown in Fig. 2 where we plot contours in the MSSM squark mass $m_{\tilde{q}}^{\mathrm{MSSM}}$ *versus* the MRSSM squark mass $m_{\tilde{q}}^{\mathrm{MRSSM}}$ plane for which the squark pro-

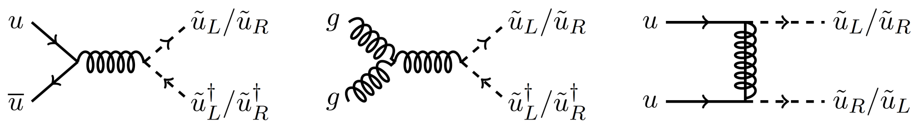

Fig. 1. Examples of tree-level diagrams for squark-pair production in the MRSSM. In contrast to the MSSM, R-symmetry forbids $\tilde{u}_\mathrm{L}\tilde{u}_\mathrm{L}$ or $\tilde{u}_\mathrm{L}\tilde{u}_\mathrm{R}^\dagger$ pairs to be produced. For simplicity, only one (s)quark flavour is shown.

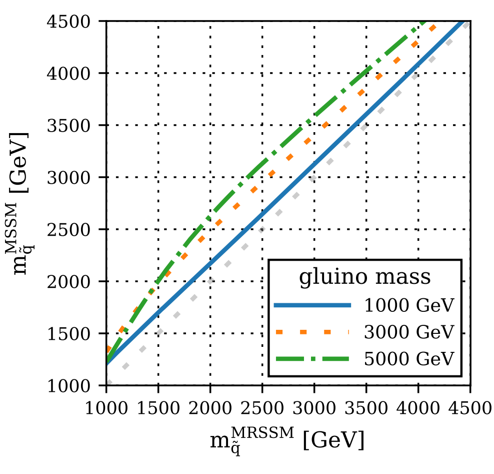

Fig. 2. Contours in the MSSM squark mass *versus* the MRSSM squark mass plane for masses for which cross sections for 1st and 2nd generation squark production are equal in both models.

duction cross sections are equal. For the gluino mass of 5 TeV, the difference is approximately 500 GeV. As we will show, result in Fig. 2 transfers almost without change to the level of semi-realistic analysis based on a fast detector response simulation.

3. Squark mass limits in the MRSSM

To extract limits on squark masses in the MRSSM, we recast available experimental analyses. To that end, we generate MRSSM and MSSM mass spectra using SARAH 4.13.0 and SPheno 4.0.3 [11–18], and use Herwig 7.1.2 [19, 20] for LO generation of Supersymmetric-QCD (SQCD) events (including subsequent decays) at the 13 TeV LHC. Events for MRSSM and MSSM are generated using UFO [21] models generated by SARAH. These events are then passed to CheckMATE 2.0.26 [22] to extract the limits for the considered parameter points[1]. Events in both models are normalized to respective NLO SQCD cross sections [27, 28].

In Ref. [9], we considered three cases:

— no flavour mixing, L/R states mass degenerate,

— no flavour mixing, independent masses of L/R states,

— stop–squark mixing, equal in L/R sectors.

In this note, we focus only on the case of no flavour mixing with L/R mass degenerate states as it exhibits the most striking difference compared to the MSSM. Figure 3 shows mass limits in the gluino mass — common squark mass plane. The relevant for this case experimental analyses are: the two to six jets plus missing transverse energy search [29] and stop searches [30, 31]. The uncertainty bands come from the estimate of missing higher order corrections and an unknown sgluon mass m_O as explained in [9]. As expected, the exclusion in gluino mass is stronger in the MRSSM because of its Dirac nature. Conversely, the limit for squark masses is weaker. As a reference, for a gluino of mass 5 TeV, we obtain following limits for squark masses:

$$m_{\tilde{q}} > \left\{ \begin{array}{l} 1.7 \text{ TeV (MRSSM)} \\ 2.3 \text{ TeV (MSSM)} \end{array} \right. \quad (m_{\tilde{g}} = 5 \text{ TeV})\,. \tag{2}$$

For a fixed squark mass of 5 TeV, the gluino must be heavier than

$$m_{\tilde{g}} > \left\{ \begin{array}{l} 2.2 \text{ TeV (MRSSM)} \\ 2.0 \text{ TeV (MSSM)} \end{array} \right. \quad (m_{\tilde{q}} = 5 \text{ TeV})\,. \tag{3}$$

[1] With CheckMATE, we make use of Delphes 3 [23], FastJet [24], the anti-k_{T} clustering algorithm [25, 26].

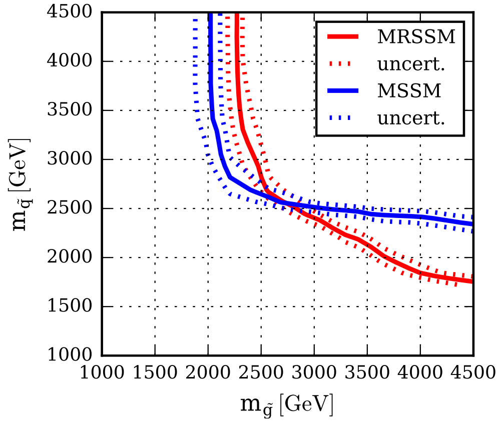

Fig. 3. Mass limits for squarks and gluino for degenerate 1$^{\text{st}}$ and 2$^{\text{nd}}$ generation masses. Uncertainty bands come from the estimate of missing higher order corrections in both models.

4. Conclusions

In this note, we have reviewed recent study of exclusion limits for squark masses in the Minimal R-symmetric Supersymmetric Standard Model. With currently available analyses, MRSSM squarks with masses below 1.7 TeV can be excluded assuming mass degenerate 1$^{\text{st}}$ and 2$^{\text{nd}}$ generation squarks and gluino of a mass of 5 TeV. The difference in the constraining power of the LHC data compared to MSSM comes almost entirely from the difference of cross sections in both models. Details like, for example, the nature of squark decay products play sub-leading, secondary role. Therefore, conclusions of our work will hold also for high luminosity phase of the LHC. It is expected that with 3000 fb^{-1} of an integrated luminosity squarks with masses up to 3 TeV can be excluded under the assumption that gluino mass is 4.5 TeV. The analogues limit in the MSSM is 3.5 TeV.

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