

(Non-minimal) SUSY

Phenomenologically interesting alternatives to the MSSM

Dominik Stöckinger

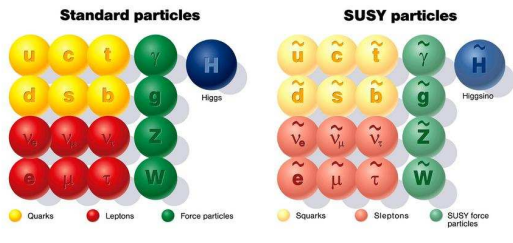
TU Dresden

LHC Days in Split, September 2016

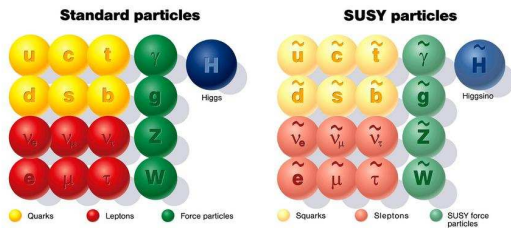
based on work with: [Philip Diessner, Jan Kalinowski, Wojciech Kotlarski, and Sebastian Liebschner '14, '15, '16]

Outline

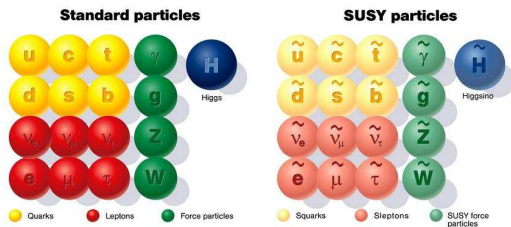
- 1 Motivation: SUSY and non-minimal SUSY
- 2 R-symmetric SUSY as a concrete example
- 3 Higgs, W, dark matter vs. LHC data in MRSSM
- 4 Summary



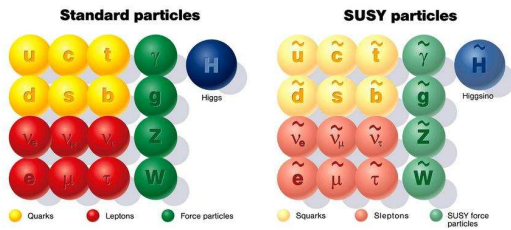
- Fundamental new symmetry, unique extension of Poincaré
- Relation to gravity, string theory



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- Fine tuning problem/stabilization of EW scale
- Unification of gauge couplings
- Dynamic generation of mexican hat potential
- Dark matter



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- **Minimality was never an argument! These motivations hold equally well in minimal and non-minimal SUSY!**

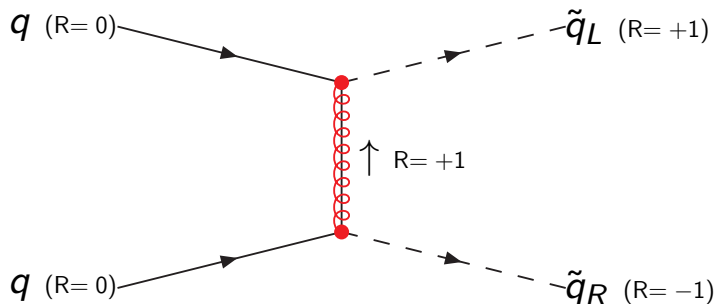


- Fundamental new symmetry, unique extension of Poincaré
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- some non-minimal models even better motivated than MSSM (improve μ -problem, flavor problem, allow lighter/heavier sparticles)

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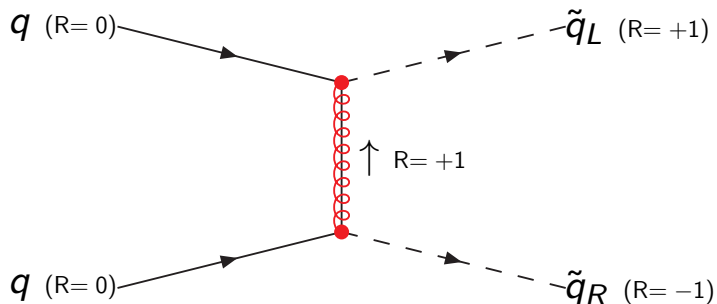
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R-symmetric model MRSSM [Kribs, Poppitz, Weiner]



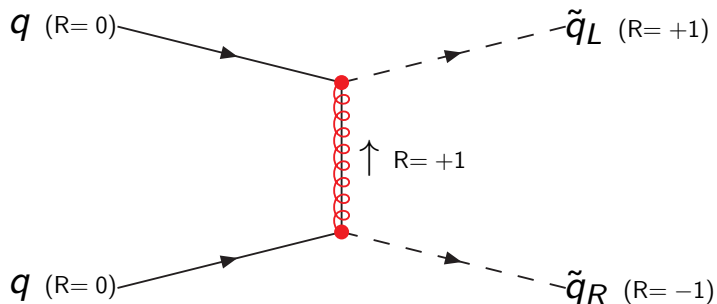
- Continuous, conserved R-charge. R-charges fixed by SUSY-algebra

(in superfields: $\theta \rightarrow e^{i\alpha\theta}$)



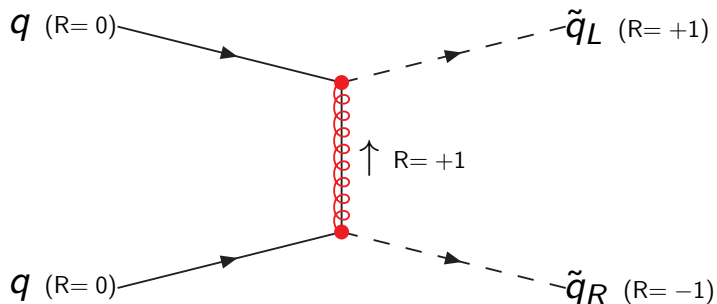
- some MSSM-processes forbidden
- surviving ones have stronger m_{gluino} -suppression

R-symmetric model MRSSM [Kribs, Poppitz, Weiner]



- gluino (and other gauginos/Higgsinos) = Dirac-fermion
 - ▶ gluon: 2 d.o.f.
 - ▶ gluino: 4 d.o.f.
 - ▶ **new scalar** sgluon: 2 d.o.f

($SU(3) \times SU(2) \times U(1)$) requires new chiral superfields (adjoint) \hat{O} , \hat{T} , \hat{S}

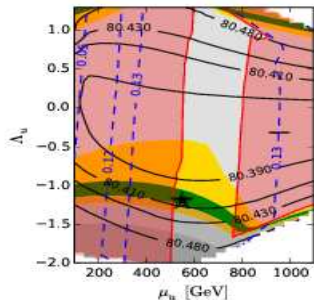
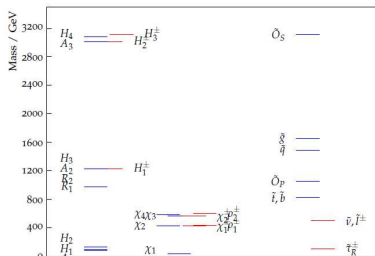


Same for all gauginos \Rightarrow new scalars

- colour octet scalars (sgluons)
- SU(2) triplet scalar (Higgs Triplet!)
- Higgs singlet

Interesting properties of MRSSM, sample scenarios

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- Dirac gauginos, and Dirac Higgsinos
- new: sgluon, Higgs triplet/singlet
- solves SUSY flavor problem



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Question 1: MRSSM compatible with Higgs, W mass measurements?

[Diessner, Kalinowski, Kotlarski, DS '14, '15]

Bad/difficulty for M_h :

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Bad/difficulty for M_h :

- more scalars S , T^0 mix, reduced tree-level mass (for $v_{S,T} \ll v$, $m_D^2 \ll m_{\text{soft}}^2$.)

$$\mathcal{M}_{\text{phi};2,3}^{\text{limit}} = \begin{pmatrix} m_Z^2 & v_u(\sqrt{2}\lambda_u\mu_u^{\text{eff-}} + g_1 m_D^B) \\ v_u(\sqrt{2}\lambda_u\mu_u^{\text{eff-}} + g_1 m_D^B) & 4(m_D^B)^2 + m_S^2 + \frac{\lambda_u^2 v_u^2}{2} \end{pmatrix}$$

- off-diag. elements=Higgsino/gaugino masses shouldn't be too large, loop corrections very important

Question 1: MRSSM compatible with Higgs, W mass measurements?

Good for M_h :

- large loop contributions to M_h from “Yukawa couplings”

y_{top} : H_U -top-quark

Λ_U : T -Dirac Higgsino superfield expression: $\Lambda_U \hat{H}_U \hat{T} \hat{R}_U$

$$(\Delta m_h)^2 \approx \frac{2v^2}{16\pi^2} \left(\frac{\Lambda^2 \lambda^2}{2} + \frac{4\lambda^4 + 4\lambda^2 \Lambda^2 + 5\Lambda^4}{4} \log \frac{m_{\text{soft}}^2}{m_D^2} \right)$$

(additional positive two-loop contributions from sgluons!)

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However, danger for M_W :

- Yukawas shouldn't be too large!

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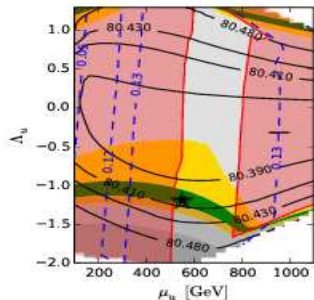
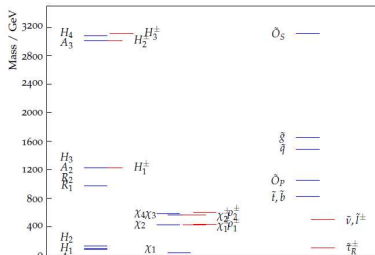
However, danger for M_W :

- Yukawas shouldn't be too large!

Answer 1: There is viable parameter space! [Diessner, Kalinowski, Kotlarski, DS '14, '15]

Interesting properties of MRSSM, sample scenarios

- R-charges forbid some processes
- Dirac gauginos, and Dirac Higgsinos
- new: sgluon, Higgs triplet/singlet
- solves SUSY flavor problem
- M_h : motivates rather light charginos
- ...and large “Yukawa coupling” Λ_u



Question 2: light singlet possible/helpful?

- Should be an advantage:
- No tree-level reduction for SM-like Higgs
- relevant H_u - S mass matrix shows the requirements:

$$\mathcal{M}_{\text{phi};2,3}^{\text{limit}} = \begin{pmatrix} m_Z^2 & v_u(\sqrt{2}\lambda_u\mu_u^{\text{eff-}} + g_1 m_D^B) \\ v_u(\sqrt{2}\lambda_u\mu_u^{\text{eff-}} + g_1 m_D^B) & 4(m_D^B)^2 + m_S^2 + \frac{\lambda_u^2 v_u^2}{2} \end{pmatrix} .$$

- small m_D^B , m_S , $\lambda_u v_u \rightarrow$ is this viable?

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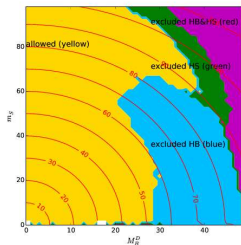
- small m_D^B , m_S , $\lambda_u v_u \rightarrow$ is this viable?

Answer 2:

Yes! Light bino Dirac mass possible!

[Diessner, Kalinowski, Kotlarski, DS '15]

Now study dark matter and LHC data!

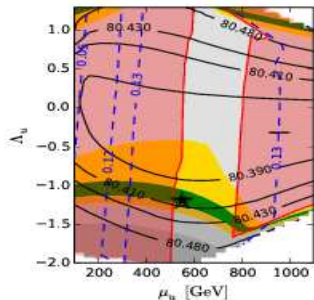
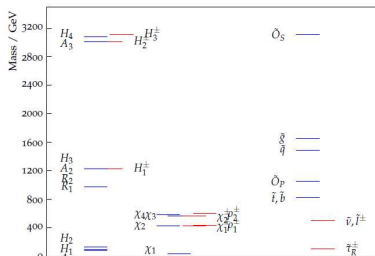


allowed region for $\lambda_u = 0$:

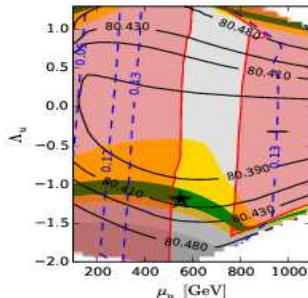
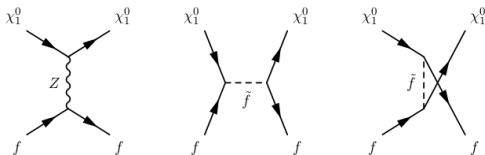
(used HiggsBounds/HiggsSignals)

Interesting properties of MRSSM, sample scenarios

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- new: sgluon, Higgs triplet/singlet
- solves SUSY flavor problem
- M_h : motivates rather light charginos
- ... and large “Yukawa coupling” Λ_u
- light singlet possible \rightarrow small m_D^B, m_s



Question 3: dark matter explained in MRSSM with(out) light singlet?



Relic density ($f = \tau$):

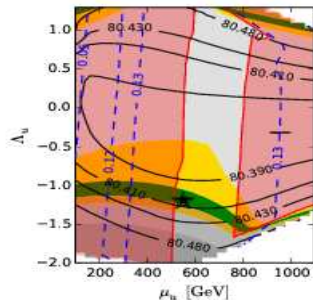
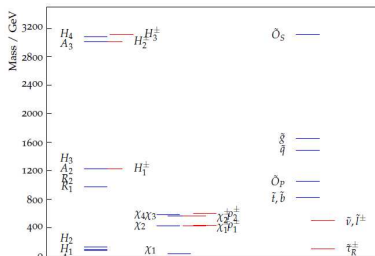
- LSP = Dirac Bino
- $m_{\text{LSP}} < 60 \dots 300 \text{ GeV}$
- annihilates into τ
- light stau mass fixed, $m_{\tilde{\tau}} - m_{\text{LSP}} < 100 \text{ GeV}$

Direct detection limits ($f = q$):

- Interference between terms $\propto \frac{1}{\mu_u^2}, \frac{1}{m_q^2}$
- $\mu_u \approx 400 \dots 700 \text{ GeV}$ preferred to evade limits

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- dark matter: LSP=Dirac Bino, light stau; $\sim 500\text{GeV}$ Higgsino μ_u preferred

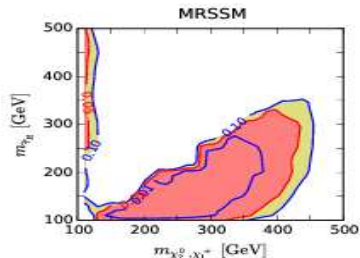
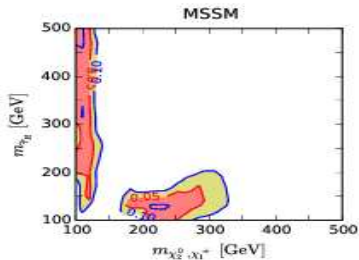


Question 4: Allowed by EW LHC searches?

Recast LHC limits for MSSM to MRSSM:

Assume very light singlet and LSP ~ 50 GeV; light stau ~ 100 GeV;

discuss limits on one degenerate neutralino/chargino $\chi^{0,\pm}$



MSSM:

- $\chi^{0,\pm}$ = wino-like
- decays to Higgs/Z/W/stau
- searches not effective

MRSSM (more dangerous!):

- $\chi^{0,\pm}$ = down-higgsino-like
- decay to stau if possible
- searches effective, but scenario alive, e.g. for $m_{\chi^{0,\pm}} \geq 350$ GeV

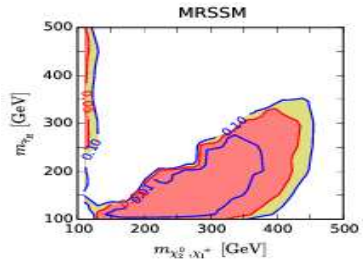
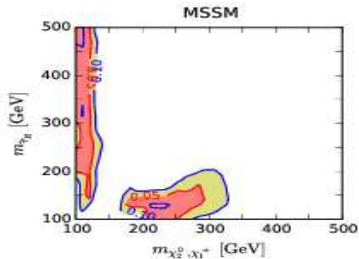
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Answer 3/4: Dark matter can be explained in this scenario!

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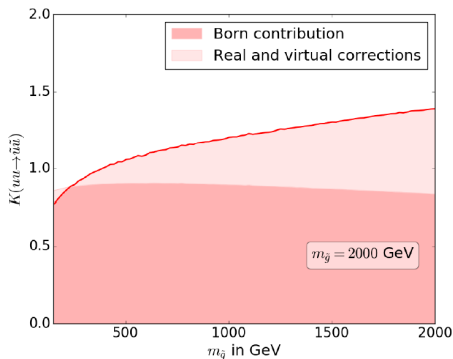
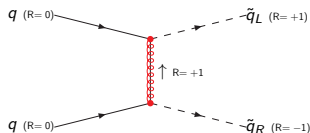
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Question 5: How about LHC searches for colored sparticles?

[DKKS+Liebschner]

Hope: total cross section reduced,
lighter masses possible!

- simple study without MRSSM NLO corrections: [Kribs, Martin '12]
“squarks in MRSSM can be a few 100 GeV lighter than in the MSSM”
- preliminary result for NLO corrections [Diessner, Kalinowski, Kotlarski, Liebschner, DS]:
K-factor in MRSSM is higher than in MSSM! Depends e.g. on gluon mass



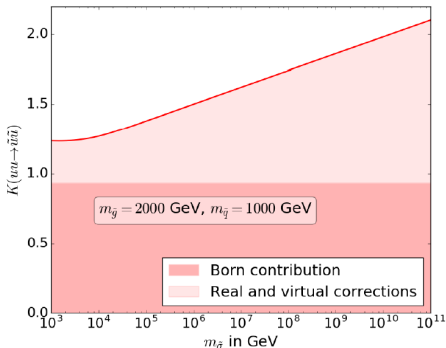
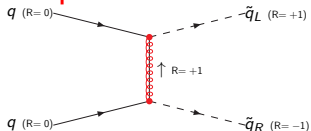
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[DKKS+Liebschner]

Lighter squarks possible!

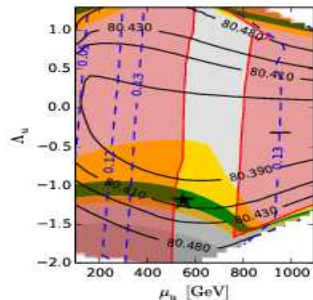
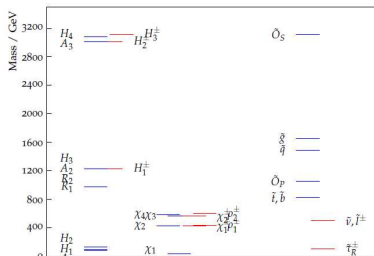
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K-factor in MRSSM is higher than in MSSM! Depends e.g. on gluon mass
- outlook: compare to LHC data!



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- light singlet possible \rightarrow small m_D^B, m_S
- dark matter: LSP=Dirac Bino, light stau; $\sim 500\text{GeV}$ Higgsino μ_u preferred
- LHC EW searches: ok
- LHC squark searches: to do precisely



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Summary and Outlook

- **Non-minimal SUSY well motivated**
 - ▶ general + model-specific motivations
 - ▶ model-specific LHC signals/limits
- **Example R-symmetry: distinct, motivated model**
 - ▶ M_W , m_h , dark matter can be explained
 - ▶ very light spectrum possible (\tilde{B} , S , $\tilde{\tau}$, $\chi^{0,\pm}$)
(Heavy singlet scenario: LSP $\sim 250\text{GeV}$)
 - ▶ Dirac fermions, new scalars
 - ▶ beautiful, more symmetry
- **Other “non-minimal” SUSY models also of interest**
 - ▶ e.g. $E_6\text{SSM}$ unifies quarks–leptons–Higgs
 - ★ predicts observable leptoquark(ino)s
 - ▶ e.g. MSSM for $\tan\beta \rightarrow \infty$
 - ★ $(g-2)_\mu$ explained for $M_{\text{LSP}} \sim 1000\text{GeV}$!

