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R-symmetric supersymmetric Higgs bosons at the LHC

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Outline

- ❖ Motivation
- ❖ Supersymmetry
- ❖ R-symmetry
- ❖ Structure of the Minimal R-symmetric Supersymmetric Standard Model
- ❖ Expectations at the LHC
production and decay modes
- ❖ Summary

Motivation

A very successful 2010 LHC run with plenty of data

The biggest question: the nature of the electroweak symmetry breaking

In the SM: Higgs mechanism  Higgs particle – the only missing piece of the SM

Although very successful, the SM is not the ultimate theory

- the Higgs sector unnatural
- matter-antimatter asymmetry
- dark matter/energy

 Hints for new physics at a TeV scale

Supersymmetry – the most elegant and respected proposition for the beyond SM physics

In the simplest realisation each SM particle is paired with a sparticle that differs in spin by $\frac{1}{2}$:

- ❖ fermions – sfermions
- ❖ gauge bosons – gauginos
- ❖ Higgses – higgsinos

SUSY problems:

- ❖ dim-4 B- and L-violating operators → extra symmetry (e.g. R-parity)
- ❖ possible flavor and CP problem due to misalignment between soft parameters and CKM → strong constraints on the parameter space

Continuous R-symmetry can ameliorate the above problems by removing

- ❖ soft tri-linear scalar couplings
- ❖ mu-term
- ❖ Majorana gaugino masses
- ❖ dim-4 B- and L-violating terms as well as dim-5 mediating proton decay

Supersymmetry

Supersymmetry: **superspace** $\{x^\mu, \theta, \bar{\theta}\}$
superfields

matter and Higgs – chiral $\hat{\Phi}(x^\mu, \theta) = \{\varphi, \psi^\alpha\}$
gauge fields – vector $\hat{G}(x^\mu, \theta, \bar{\theta}) = \{\tilde{G}^\alpha, G^\mu\}$

Lagrangian

❖ **kinetic terms** $\int d^2\theta d^2\bar{\theta} \hat{\Phi}^\dagger e^{-2g\hat{G}} \hat{\Phi} + (\int d^2\theta \hat{G}^\alpha \hat{G}_\alpha + h.c.)$

where $\hat{G}^\alpha \sim \bar{D}^2 D^\alpha \hat{G}$ field-strength superfield

❖ **potential** $\int d^2\theta W$ where superpotential

$$W \sim \mu \hat{H}_d \hat{H}_u + y_d \hat{H}_d \hat{Q} \hat{D}^c + \dots$$

❖ **soft-SUSY breaking**: tri-linear scalar couplings and soft masses

R-symmetry

R-symmetry – a continuous U(1) global symmetry under $\theta \rightarrow e^{i\alpha}\theta$

Grassmann coordinates have non-trivial R-charge

$$R(\theta) = +1, \quad R(d\theta) = -1, \quad R(\bar{\theta}) = -1, \quad R(d\bar{\theta}) = +1$$

superfields $\hat{X}_i(x^\mu, \theta, \bar{\theta}) \rightarrow e^{i\xi_i\alpha} \hat{X}_i(x^\mu, e^{i\alpha}\theta, e^{-i\alpha}\bar{\theta})$

component fields have different R-charge

gauge $R(\hat{G}) = 0 \quad \Rightarrow R(G^\mu) = 0, \quad R(\tilde{G}^\alpha) = +1$

kinetic terms are automatically R-symmetric

chiral

matter $R(\hat{q}) = +1 \quad \Rightarrow R(\tilde{q}) = +1, \quad R(q) = 0$

Higgs $\overset{m = 200 \text{ GeV}}{R(\hat{H}) = 0} \quad \Rightarrow R(H) = 0, \quad R(\tilde{H}) = +1$

R-symmetry

terms allowed:

Yukawa $y_d \hat{H}_d \hat{Q} \hat{D}^c$

scalar masses $M_{\tilde{q}}^2 |\tilde{q}|^2$

terms forbidden

mu-term $\mu \hat{H}_d \hat{H}_u$

L- and B-violation $\hat{L} \hat{Q} \hat{D}^c$

tri-linear scalar couplings $A \tilde{H}_d \tilde{Q} \tilde{D}^c$

Majorana gaugino masses $M_{\tilde{G}} \tilde{G}^\alpha \tilde{G}_\alpha$

Minimal R-symmetric SSM

The field content of MRSSM: fields of the MSSM with addition of

- chiral superfields in the adjoint rep. of the corresponding gauge group

$$\hat{\Sigma} = \{\sigma, \tilde{G}'^\alpha\}$$

$$R(\hat{\Sigma}) = 0 \quad \Rightarrow \quad R(\sigma) = 0, \quad R(\tilde{G}'^\alpha) = -1$$

to build a Dirac gaugino mass $M^D \tilde{G}^\alpha \tilde{G}'_\alpha$

- two chiral iso-doublets \hat{R}_u, \hat{R}_d with R-charge 2

to build a mu-type term $\mu_d \hat{H}_d \hat{R}_d + \mu_u \hat{H}_u \hat{R}_u$

and in addition $\lambda_d^i \hat{H}_d \hat{\Sigma}^i \hat{R}_d + \lambda_u^i \hat{H}_u \hat{\Sigma}^i \hat{R}_u, \quad i = I, Y$

MRSSM

R-charges of the superfields and their component fields

Field	Superfield		Boson		Fermion	
Matter	$\hat{Q}, \hat{D}^c, \hat{U}^c$	+1	$\tilde{Q}, \tilde{D}^c, \tilde{U}^c$	+1	Q, D^c, U^c	0
Higgs	$\hat{H}_{d,u}$	0	$H_{d,u}$	0	$\tilde{H}_{d,u}$	-1
	$\hat{R}_{d,u}$	+2	$R_{d,u}$	+2	$\tilde{R}_{d,u}$	+1
Gauge Vector	\hat{G}	0	G_μ	0	\tilde{G}	+1
Gauge Chiral	$\hat{\Sigma}$	0	σ	0	\tilde{G}'	-1

Physical fields: matter, gauge and Higgs fields as in the MSSM

Dirac gluinos and neutralinos

additional pair of charginos

gauge-adjoint scalars (e.g. sgluons)

R-Higgs bosons

Higgs sector

Higgs potential

(assuming electroweak adjoints heavy)

$$\begin{aligned}\mathcal{V}_{HR}^0 = & (m_{H_d}^2 + \mu_d^2)|H_d^0|^2 + (m_{H_u}^2 + \mu_u^2)|H_u^0|^2 - (B_\mu H_d^0 H_u^0 + \text{h.c.}) \\ & + (m_{R_d}^2 + \mu_d^2)|R_d^0|^2 + (m_{R_u}^2 + \mu_u^2)|R_u^0|^2 \\ & + |\lambda_d^I H_d^0 R_d^0 + \lambda_u^I H_u^0 R_u^0|^2 + |\lambda_d^Y H_d^0 R_d^0 - \lambda_u^Y H_u^0 R_u^0|^2 \\ & + \frac{1}{8}(g^2 + g'^2) (|H_d^0|^2 - |H_u^0|^2 - |R_d^0|^2 + |R_u^0|^2)^2 .\end{aligned}$$

Important consequences:

- R-Higgses do not develop vev's
- H-Higgses and R-Higgses do not mix

R-Higgses

Conserved R-charge restricts couplings of R-Higgs bosons

allowed: $R\tilde{\ell}\tilde{\ell}, R\tilde{q}\tilde{q}, R\tilde{\chi}\tilde{\chi}, RRH, RRV$

vanishing: Rff, RVV, RHH

Decay modes: only to pairs of sparticles

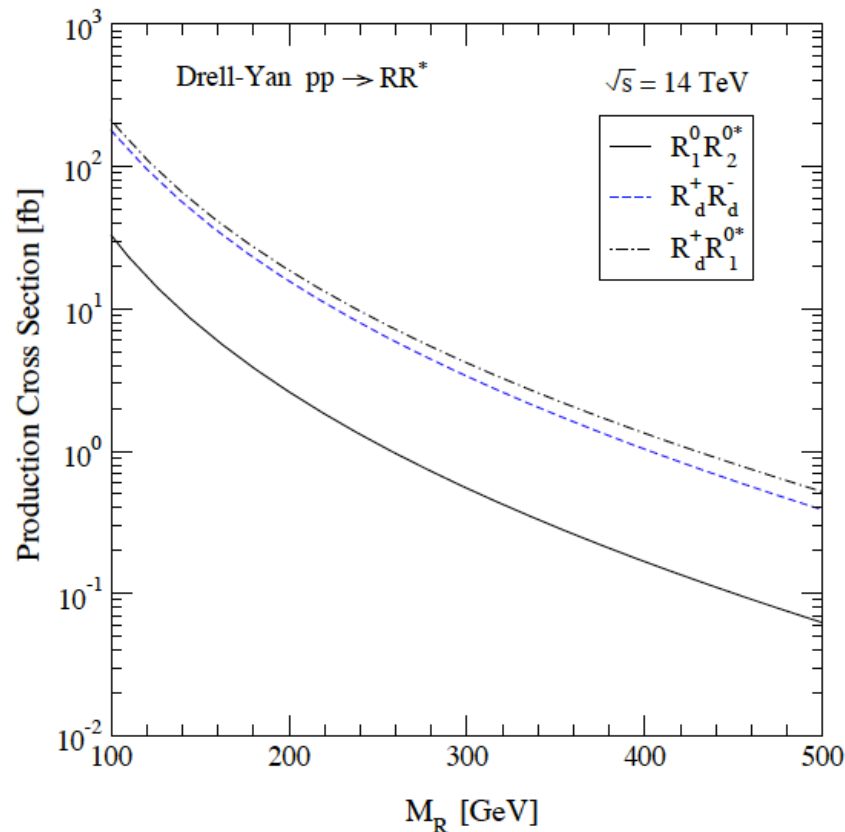
$$\Gamma[R \rightarrow \tilde{f}_L \tilde{f}_R^*] = \frac{\lambda^{1/2} \tilde{\alpha}_{Rff'}^2}{16\pi M_R}$$
$$\Gamma[R \rightarrow \tilde{\chi}_{Dj} \tilde{\chi}_{Dk}] = \frac{\lambda^{1/2}}{8\pi M_R} \{ \alpha_{Rjk}^2 [M_R^2 - (m_j + m_k)^2] + \alpha'_{Rjk}{}^2 [M_R^2 - (m_j - m_k)^2] \}$$

Production channels: only in pairs via Drell-Yan

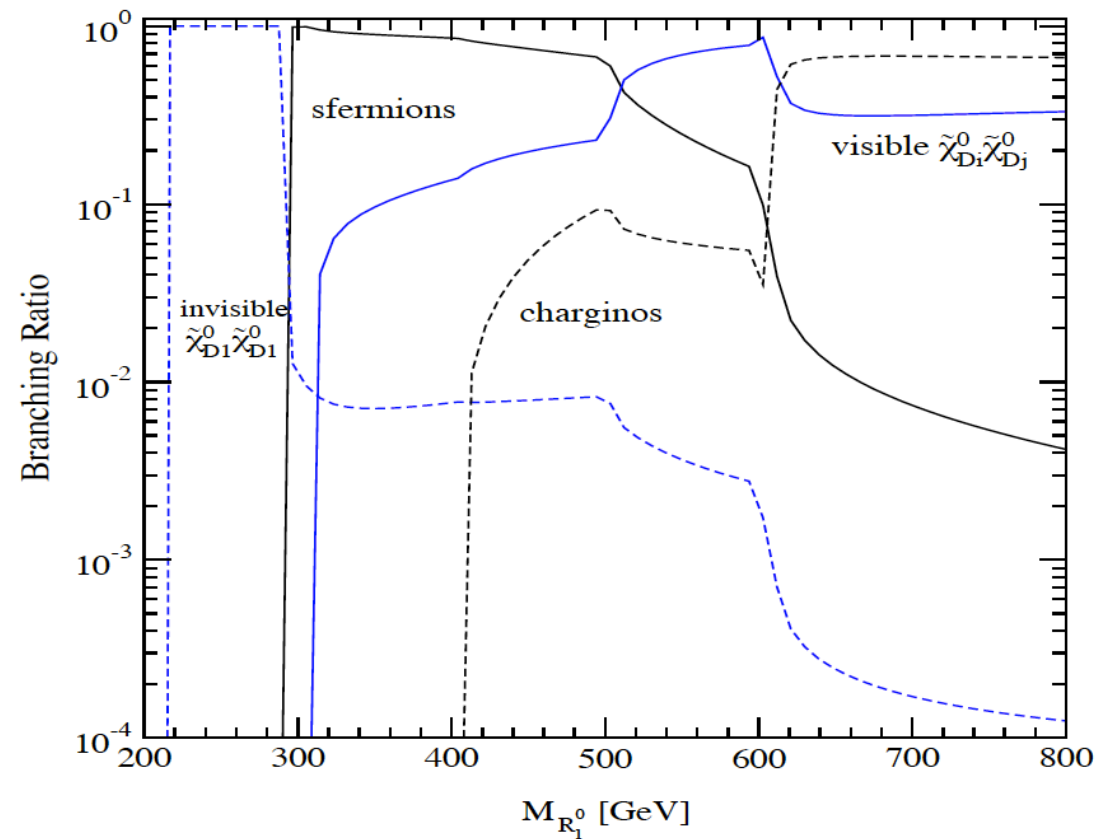
$$\sigma[pp \rightarrow RR^*] = \sum_{q\bar{q}} \left\langle \frac{\pi\lambda^{3/2}}{9s} \left| \sum_V \alpha_{RRV} \frac{s}{s - m_V^2} \alpha_{qqV} \right|^2 \right\rangle_{q\bar{q}}$$

Expectations at the LHC

Production:



Branching ratios:



other parameters as in the SPS1a' scenario (with Dirac gauginos)

Expectations at the LHC

Other production channels:

cascade decays: $\tilde{q} \rightarrow q\tilde{\chi}_n \rightarrow q\tilde{\chi}_1 R$

gamma fusion $pp \rightarrow \gamma\gamma \rightarrow RR^*$

Expectations at the LHC

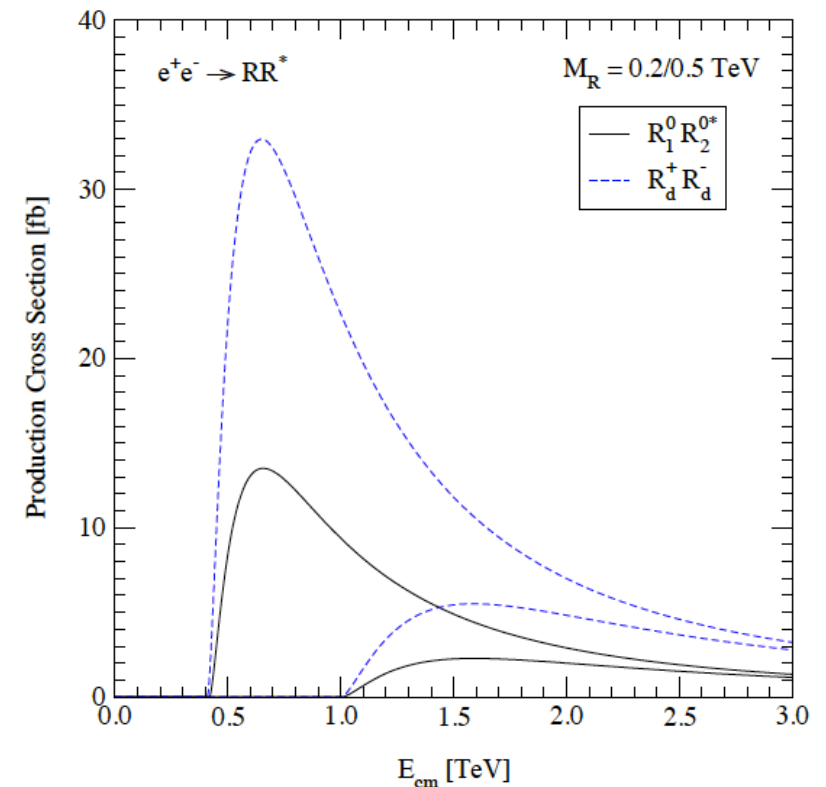
Other production channels:

cascade decays: $\tilde{q} \rightarrow q\tilde{\chi}_n \rightarrow q\tilde{\chi}_1 R$

gamma fusion $pp \rightarrow \gamma\gamma \rightarrow RR^*$

for heavier R-Higgs: wait for CLIC

$$\sigma[e^+e^- \rightarrow RR^*] = \frac{\pi\lambda^{3/2}}{3s} \left| \sum_V \alpha_{RRV} \frac{s}{s - m_V^2} \alpha_{eeV} \right|^2$$



Summary

- Well motivated R-symmetric SUSY model discussed
- Ameliorates the flavour and CP problems
- Gauginos become Dirac particles
- R-scalars expand significantly the scalar sector
- Conserved R-charge restricts production channels and decay modes
- Other sectors (colored, -inos) not discussed here

distinct phenomenology at colliders
consequences for DM relic abundance

Backups

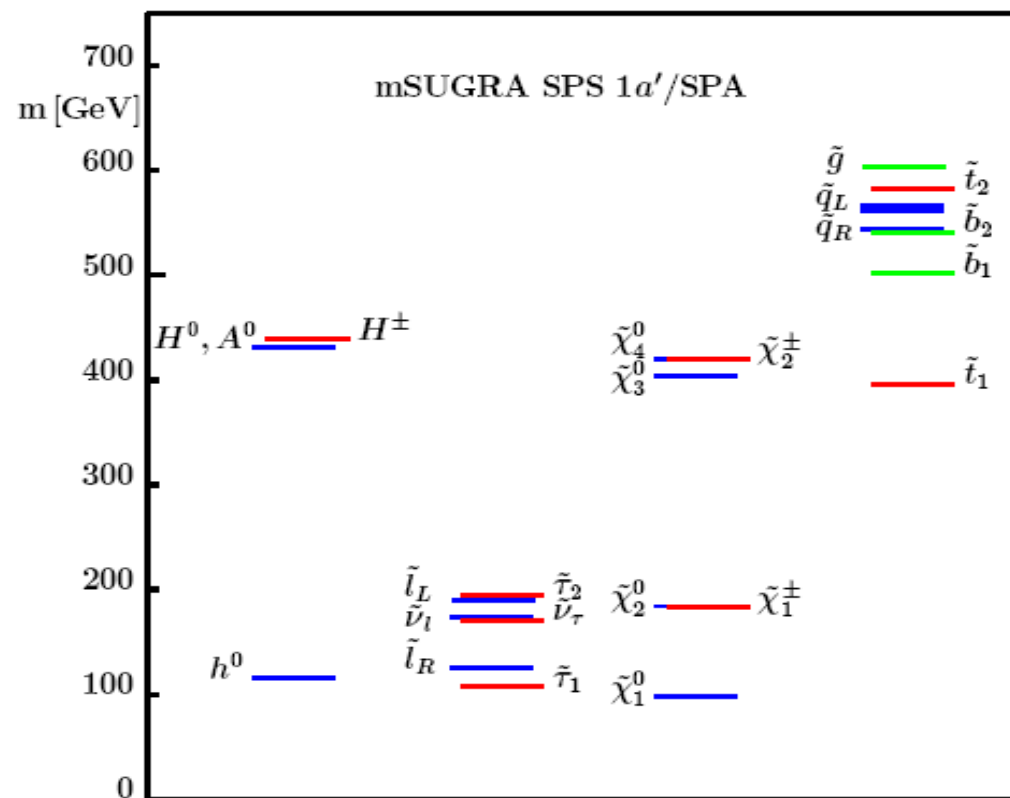
soft masses

B _{mu} -term	$\int d^2\theta d^2\bar{\theta} \frac{X^\dagger X}{M^2} \hat{H}_u \hat{H}_d \rightarrow B_\mu H_u H_d$
scalar masses for R-Higgses	$\int d^2\theta d^2\bar{\theta} \frac{X^\dagger X}{M^2} \hat{R}_u^\dagger \hat{R}_d \rightarrow M_{R_d}^2 (R_d^+ ^2 + R_d^0 ^2)$
scalar masses for sigma fields	$\int d^2\theta d^2\bar{\theta} \frac{\hat{W}^\alpha \hat{W}_\alpha}{M^2} \text{Tr} \hat{\Sigma}^2 \rightarrow M_\sigma^2 (\sigma^2 + \sigma^{*2})$
Dirac gaugino masses	$\int d^2\theta d^2\bar{\theta} \frac{\hat{W}^\alpha}{M} \hat{G}_\alpha \hat{\Sigma} \rightarrow M^D \tilde{G} \tilde{G}'$

when hidden sector spurion fields develop vevs

$$\begin{aligned}\langle X \rangle &= \theta^2 F \\ \langle \hat{W}^\alpha \rangle &= \theta^\alpha D\end{aligned}$$

SPS1a' scenario



m_0	70 GeV
$m_{1/2}$	250 GeV
A_0	-300 GeV
$\tan \beta$	10
$\text{sign } \mu$	+

