Higgs bosons in a model of spontaneous R-parity violation

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Outline

- Motivating spontaneous R-parity violation
- Field content and previous motivation to study the model
- Properties of the scalar sector: masses, couplings and mixing
- Conclusions

This talk is based on the work (in preparation) of Katri Huitu and HW.
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Where is supersymmetry hiding?

The Standard Model is excellent, but. . .

- neutrinos are massless in SM $\Rightarrow$ no neutrino oscillation
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Supersymmetric models can solve these problems, but. . .

- superpartners are still unobserved, though they were expected to be within the reach of 7-8 TeV phase of LHC
- the observed Higgs mass is close to the upper limit or above it for all minimal supersymmetric models
- the Higgs mass needs large A-terms and/or heavy stops

Possible solution: spontaneous R-parity violation

- R-parity is an additional assumption in supersymmetric models to avoid baryon and lepton number violating operators
- The R-parity violating superpotential can be written as $W_{RPV} = \lambda_{ijk} L_i L_j E_k + \lambda'_{ijk} L_i Q_j D_k + \lambda''_{ijk} U_i D_j D_k + \mu_i L_i H_u$

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- Spontaneous RPV is more predictive: *QLD*- and *LLE*-type operators are correlated

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- Spontaneous RPV is more predictive: *QLD*- and *LLE*-type operators are correlated
- Good thing: LSP is unstable $\Rightarrow$ SUSY searches relying on MET do not hold
- Problem: LSP is unstable $\Rightarrow$ No cold dark matter candidates

The superpotential

The model was first introduced by Kitano and Oda (PRD61, 113001). We add to the MSSM field content a Higgs singlet Φ and three singlet neutrinos N_i.

The superpotential

$$W = W'_{MSSM} + h^{\nu}_{ij}(L_i \cdot H_u)N_j + \lambda_H (H_u \cdot H_d)\Phi + \lambda_{N_i} N_i^2 \Phi/2 + \lambda_\Phi \Phi^3/6$$

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- The term $N^2\Phi$ breaks lepton number explicitly $\Rightarrow$ no spontaneous breaking of a global symmetry $\Rightarrow$ would-be-majoron gets a mass
- The domain wall problem due to the breaking of the Z_3 symmetry is similar to NMSSM and can be taken care of

Soft supersymmetry breaking terms

$$\mathcal{L} = \mathcal{L}'_{MSSM} + m^2_{N_i}|\tilde{N}_i|^2 + m^2_\Phi|\Phi|^2 + A^{\nu}_{ij}(\tilde{L}_i \cdot H_u)\tilde{N}_j + A_H(H_u \cdot H_d)\Phi + A_{N_i}\tilde{N}_i^2\Phi/2 + A_\Phi \Phi^3/6 + \xi^3\Phi + \mathrm{h.c.}$$

Neutrino mass generation and R-parity violation

- Neutrino masses can be generated by the type-I seesaw with the help of N fields
- Neutrino masses can also be generated with the help of neutrino-neutralino mixing
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- In MSSM this leads to a charged vacuum, now we wish to give the VEV to a sneutrino field
- The field with the smallest Yukawa coupling gets the VEV $\Rightarrow$ set h^{ν} small $\Rightarrow \langle \tilde{N} \rangle \neq 0$
- Sneutrino VEVs make the low energy effective theory look like bilinear R-parity violation$\Rightarrow$ only three RPV parameters in the superpotential

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- $\langle \tilde{\nu} \rangle$ also constrained by neutrino masses to be around 1 MeV or less
- Since $\langle \tilde{\nu} \rangle$ is small, doublet sneutrinos decouple from the other scalars as do those combinations of singlet sneutrinos that do not have a VEV

$\Rightarrow$ Concentrate on H_u, H_d, $\tilde{N}$ and Φ

Lightest neutral CP-even scalar — how to get a 125 GeV Higgs?

- Since there are singlets, one might expect that the lightest CP-even scalar would have the same tree-level mass limit as in the NMSSM
- The NMSSM limit is derived by looking at the 2×2 submatrix formed by H_u and H_d
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- Need to look at the 3×3 submatrix $\Rightarrow$ we get an upper bound $m \leq m_Z$ at tree-level as in the MSSM!
- Two ways to get the SM-like Higgs mass up to 125 GeV: large A-terms (RPV requires them) or a lighter singlet scalar (usually mostly sneutrino)

Numerical analysis

- One-loop effective potential with top-stop and bottom-sbottom corrections
- Random scan over all relevant parameters of the Higgs sector
- Check that scalar potential after EWSB and RPV is below the symmetric state
- Require tree-level neutrino mass (0.05–0.5 eV) and SM-like Higgs mass (120–130 GeV) to be within the correct range
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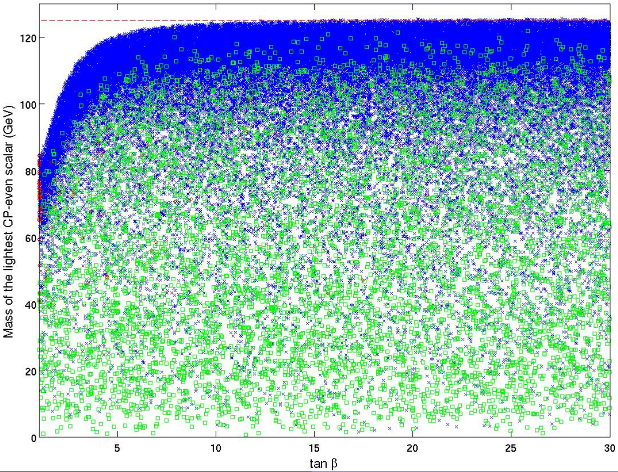
Cutflow

Total points	500 000
$\langle H_u \rangle, \langle H_d \rangle, \langle \Phi \rangle, \langle \tilde{N} \rangle \neq 0$ gives a minimum	438 802
Neutrino and Higgs constraints satisfied	14 658

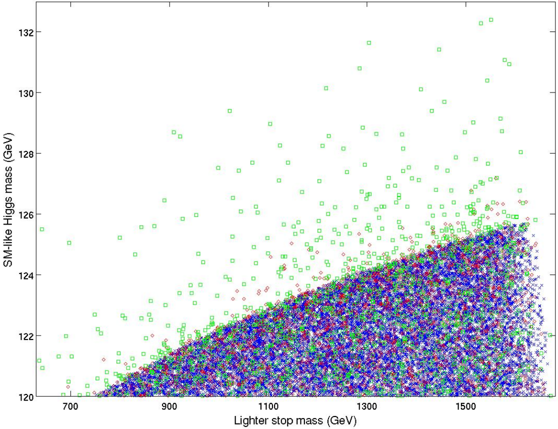
The lightest CP-even scalar mass can reach 126 GeV

Up-type Higgs — blue, down-type Higgs — red, sneutrino — green

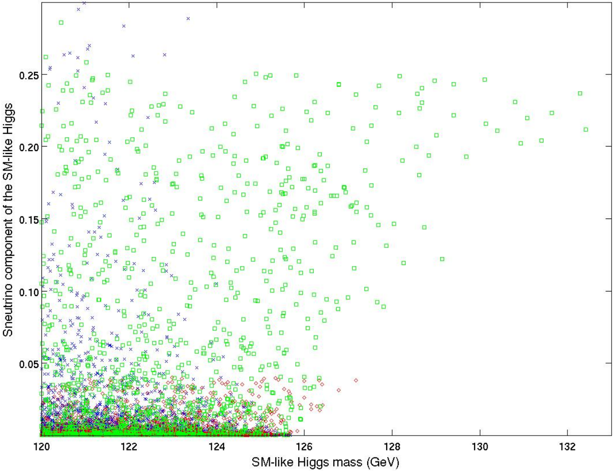


SM-like Higgs mass

The SM-like Higgs mass may go up to 132 GeV (blue: SM-like Higgs lightest, red: singlet below 80 GeV, green: between 80–120 GeV)



Higgs-sneutrino mixing

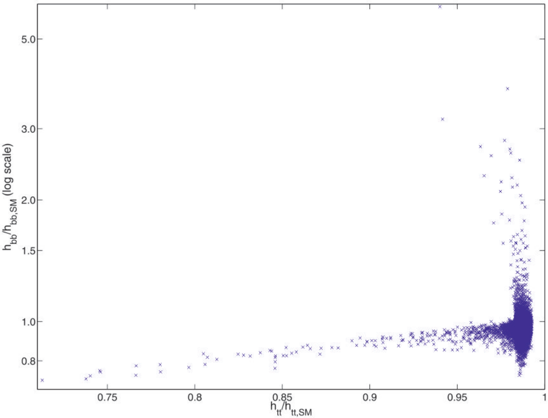


Some remarks

- The observed Higgs mass may be reached in this model
- The SM-like Higgs mass can be higher than in the MSSM
- The same SM-like Higgs mass can be achieved with 500 GeV smaller stop masses than in the MSSM if a lighter mostly singlet state exists
- The highest Higgs masses require Higgs-sneutrino mixing
- LEP limits for hZZ coupling below 80 GeV are restrictive to allow the Higgs mass to be lifted too much
- The interesting possibility is a sneutrino-Higgs mixed state between 80 and 120 GeV

Couplings of the SM-like Higgs: bottom vs. top

With SUSY-QCD corrections ($M_{\tilde{g}} = 1.5$ TeV)



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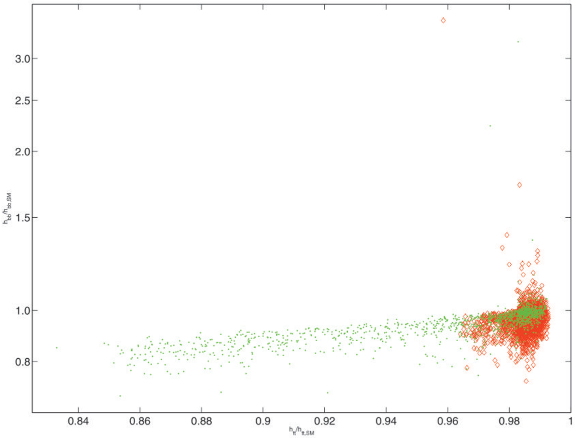
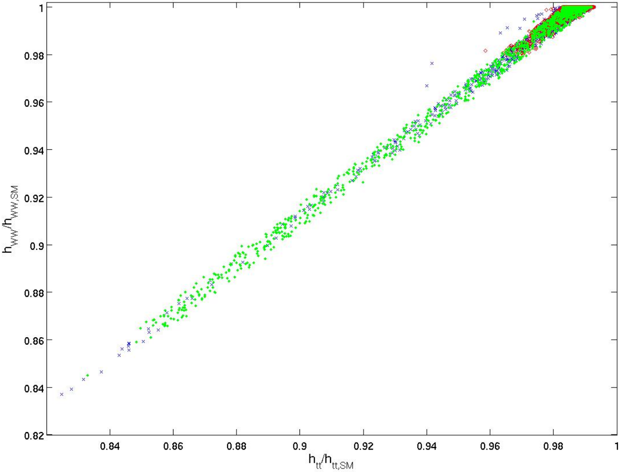
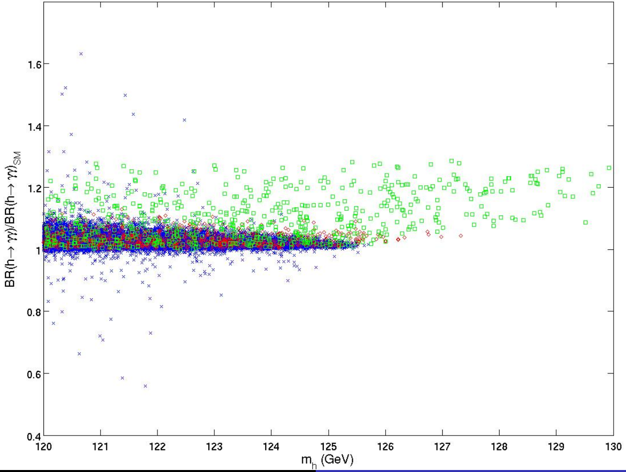


Couplings of the SM-like Higgs: W vs. top



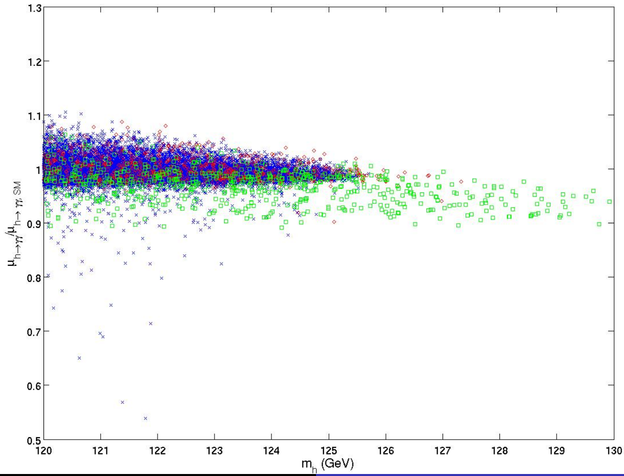
Branching ratio of $h \to \gamma\gamma$

The branching ratio to two photons may be slightly enhanced



Event rate of $h \to \gamma\gamma$

The event rate is suppressed if there is large Higgs-sneutrino mixing



Remarks on the couplings

- In any case the majority of points are very close to the SM values
- Couplings to top and W are almost identical compared to SM expectation
- SUSY-QCD corrections for TeV scale SUSY partners may cause deviations in the bottom quark coupling, while Higgs-sneutrino mixing may lead to a universal suppression of couplings
- Small enhancement in the two-photon branching ratio possible, but event rate close to SM

The CP-odd neutral scalar sector

- The lightest CP-odd scalar is usually the would-be-majoron, at least if λ_N and v_Φ are relatively small
- Since the would-be-majoron gets its mass from the $\lambda_N N^2 \Phi$-term, it is a mixture of singlets
- The large A-terms tend to make the CP-odd scalars quite heavy
- The CP-odd sector seems to be hard to detect experimentally

Conclusions

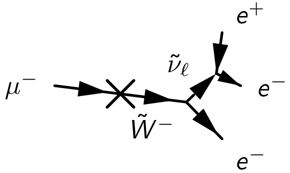
- The model seems to be viable in those aspects that we studied
- Spontaneous R-parity violation leads to some interesting effects in the Higgs sector
- The SM-like Higgs boson can have a mass of $\sim$ 125 GeV
- If there is a lighter, mostly single scalar, we may have quite light stops despite the large Higgs mass
- The couplings are generally SM-like though deviations due to SUSY-QCD corrections or Higgs-sneutrino mixing are possible

Parameter ranges

Parameter	Minimum value	Maximum value
$\tan\beta$	1	30
λ_N	0.1	0.8
λ_Φ	0.05	0.25
λ_H	-0.1	0.4
h_ν	10^{-8}	10^{-6}
A	-6000	-1000
ξ	-3500	-500
v_Φ	600	2500
v_N	50	4000
v_ν	10^{-6}	$5 \cdot 10^{-4}$
$m_{\tilde{Q}_L,\tilde{t}_R,\tilde{b}_R}$	700	1700

Avoiding flavor constraints

Many of the constraints of flavor physics are satisfied since they need the mixing of the lepton and Higgs doublets, which is very small ($\propto h^\nu$).
For instance, the tree-level process $\mu \to 3e$, whose branching ratio has the experimental limit of 10^{-12} proceeds dominantly via the following diagram:



The branching ratio is of the order of
$3 \cdot 10^{-30} \times (v_\nu/1\,\mathrm{MeV})^2(\sin\gamma/10^{-4})^2(100\,\mathrm{GeV}/m_{\tilde{\nu}})^4 \tan^4\beta \ll 10^{-12}$

What about the light sneutrino?

- If the light particle is a pure singlet sneutrino, it will be very hard to produce; it doesn't couple to quarks or gauge bosons and leptonic couplings are suppressed by h^ν
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- If there is a substantial component of doublet Higgs, usual Higgs production mechanisms become available (with suppression)
- The only unsuppressed (by h^{ν}) kinematically available decay mode is $\tilde{N} \to \gamma\gamma$, which proceeds via a charged Higgs loop; if the charged Higgs is heavy, this mode will also be suppressed
- Hence the sneutrino may look like a usual Higgs boson with very much suppressed couplings to all particles but with an enhanced $\gamma\gamma$ branching ratio