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A light singlet at the LHC and DM

of the R-symmetric supersymmetric model

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NATIONAL SCIENCE CENTRE POLAND

Summary

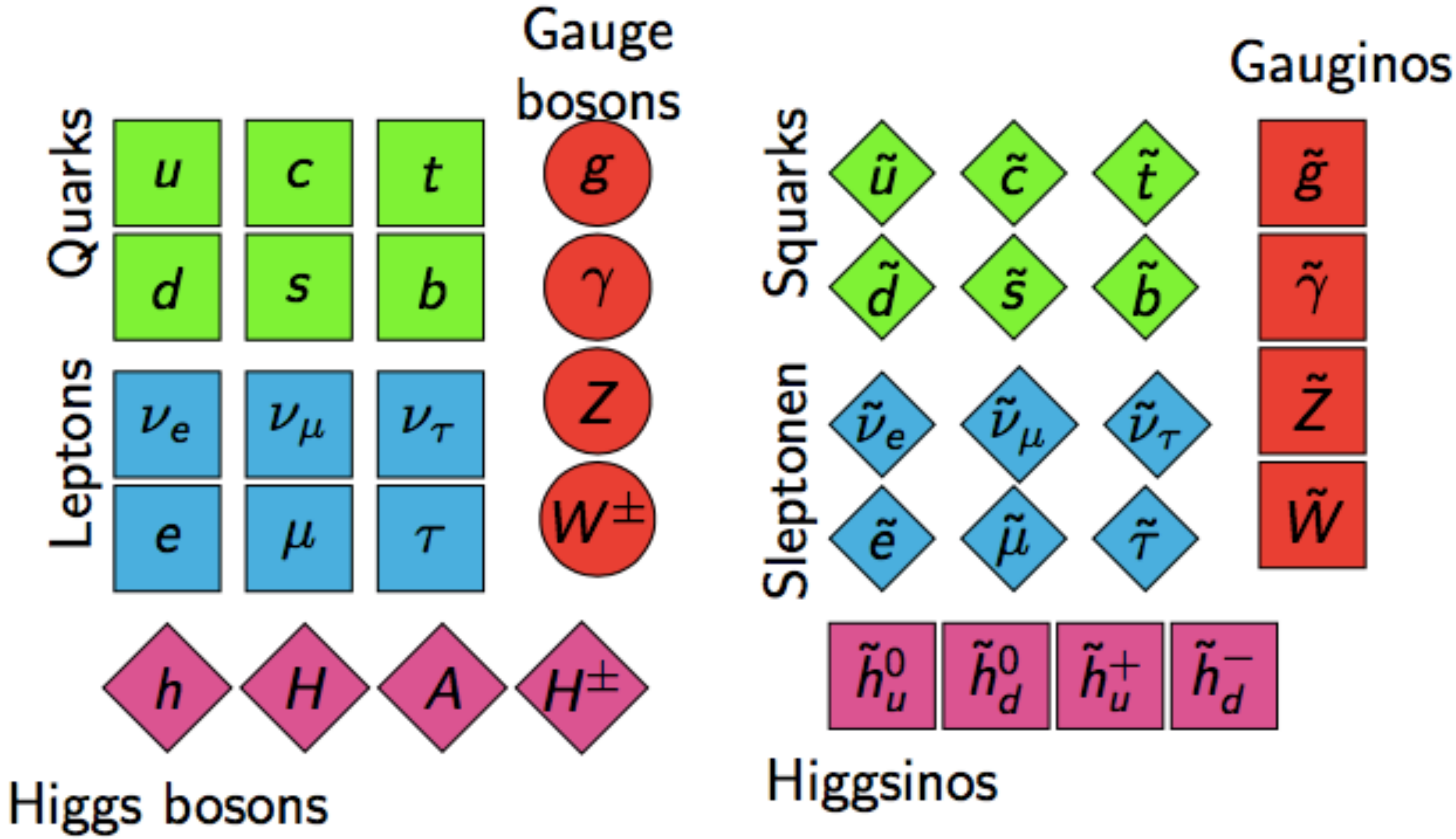
- Well motivated R-symmetric SUSY model
- SUSY flavor problem relaxed, Dirac gauginos and higgsinos
- Extended Higgs sector with unconventional phenomenology
- Viable benchmarks with
  - ~ 125 GeV Higgs boson mass
  - agreement with EWPO and flavor physics
  - stable vacuum
- Scenario with a light singlet is very predictive
  - consistent with LHC constraints
  - viable candidate for dark matter
  - some states light and could be seen at the LHC

Outline

- Introduction
  - SUSY with R-symmetry
  - MRSSM
- Higgs sector
  - Higgs boson masses
  - electroweak observables
- Confronting the experiment
  - light singlet phenomenology
  - LHC constraints
  - dark matter connection
- Summary

Based on papers JHEP 1412 (2014) 124, Adv. HEP (2015) 760729,
JHEP 1603 (2016) 007, Acta Phys.Polon.B (2016) 203, PoS LL2016, 012.

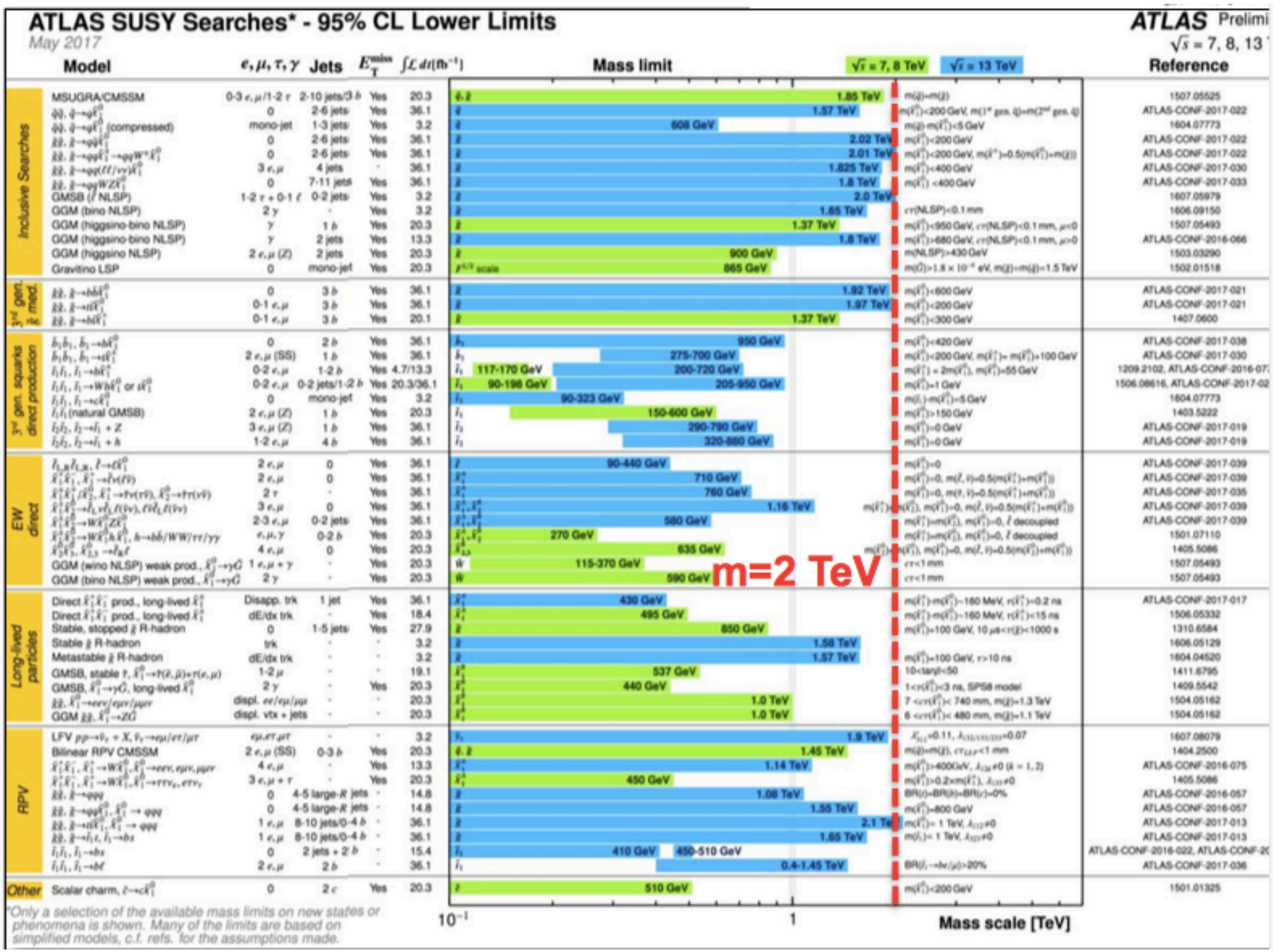
Minimal supersymmetry



- ✓ Solves hierarchy problem
- ✓ LSP can be DM candidate

➡ Expect some SUSY states directly to show up at LHC

Experimental searches



Going beyond the MSSM

LHC Run 2 on-going: so far no sign of SUSY

Possibilities:

- No supersymmetry
- Non-minimal SUSY
  - More Higgs – NMSSM, THMSSM, ...
  - More gauge – USSM, E6SSM, BLSMMS, ...
  - Less symmetry – RPV, split SUSY
  - More symmetry – R-symmetry, ⋯

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    - ⋯

Our choice ➔ R-symmetry

R-symmetry

Additional symmetry allowed by Haag-Łopuszański-Sohnius Theorem

R-symmetry almost as old as SUSY itself

[Fayet '76; Salam & Strathdee '76 , ...]

For N=1 SUSY it is a continuous U(1) global symmetry under

$$\theta \to e^{i\alpha}\theta$$

[Chamseddine&Dreiner '95,..]

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

➔ component fields have different R-charge

Symmetry or Parity ?

Transformation of superfield

$$\exp(i\tau R)F(x^\mu,\theta,\overline{\theta})\exp(-i\tau R) = \exp(i\tau Q_R)F(x^\mu,\exp(-i\tau)\theta,\exp(i\tau)\overline{\theta})$$

$\tau \in \{0, 2\pi\}$

For R-parity τ fixed, as Z_2: $\tau = n\pi$

$$n \text{ odd} \Rightarrow \exp(-i\tau) = \exp(i\tau) = -1$$
$$n \text{ even} \Rightarrow \exp(-i\tau) = \exp(i\tau) = 1$$

End up with matter parity $((-1)^{3B+L+2S})$

R-symmetry

Lagrangian has to be invariant under $\theta \to e^{i\alpha}\theta$

$\hat{G}^{\alpha} \sim \bar{D}^2 D^{\alpha} \hat{G}$

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

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

➡ are automatically R-symmetric

- Superpotential $\int d^2\theta\; W$ ➡ must have R=2

- Soft breaking terms ➡ must have R=0

R-sym: consequences for model building

- soft gaugino masses R($M_{\tilde{G}} \tilde{G}^\alpha \tilde{G}_\alpha$)=2 ⟶ forbidden

- freedom to assign the R-charges to chiral superfields

MRSSM: SM particles have R=0, superpartners R≠0

[Kribs Poppitz Weiner 2007]

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

Higgs $R(\hat{H}) = 0 \quad \Rightarrow \quad R(H) = 0, \quad R(\tilde{H}) = -1$

other choices:

Frugiuele, Gregoire
Frugiuele, Gregoire, Kumar, Ponton
Davies, March-Russell, McCullough
Riva, Biggio, Pomarol

R-sym: consequences for model building

terms allowed:

- superpotential: Yukawa $y_d \hat{H}_d \hat{Q} \hat{D}^c$
- soft terms: scalar masses $M^2_{\tilde{q}} |\tilde{q}|^2$

also ΔL=2 Majorana neutrino mass $\hat{H}_u \hat{L} \hat{H}_u \hat{L}$ allowed

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terms forbidden:

- superpotential
  - mu-term $\mu \hat{H}_d \hat{H}_u$
  - L- and B-violation $\hat{L}\hat{Q}\hat{L}$, $\hat{H}_u \hat{L}$
- soft terms:
  - tri-linear couplings $A_d H_d \tilde{Q} \tilde{d}^*$
  - Majorana masses $M_{\tilde{G}} \tilde{G}^\alpha \tilde{G}_\alpha$

R-sym: consequences for model building

Good: R-symmetry ameliorates SUSY flavor problems by removing

- dim-4 B- and L-violating terms, and dim-5 in proton decay
- soft tri-linear scalar couplings
- some MSSM contributions to flavor-violating observables forbidden

R-sym: consequences for model building

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But: mu-term and Majorana masses are forbidden,
need new means to give masses to gauginos/higgsinos

- Solution for gauginos: Dirac masses $M_i^D \tilde{\lambda}_i^a \psi_j^a$

  where $\tilde{\lambda}_i^a$ from vector , and ψ_j^a from additional chiral superfield

  ➡ Need chiral superfields in adjoint representations: $\hat{O}, \hat{T}, \hat{S}$

- Solution for higgsinos: $\mu_d \hat{H}_d \hat{R}_d + \mu_u \hat{H}_u \hat{R}_u$

  ➡ Need two chiral superfields with R=2: $\hat{R}_{d,u}$

MRSSM

[Kribs Poppitz Weiner 2007]

R-charges of the superfields and their component fields

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	$\hat{O}, \hat{T}, \hat{S}$	0	O, T, S	0	$\tilde{O}, \tilde{T}, \tilde{S}$	−1

MRSSM

[Kribs Poppitz Weiner 2007]

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Physical fields: matter, gauge and Higgs as in MSSM

MRSSM

[Kribs Poppitz Weiner 2007]

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matter, gauge and Higgs as in MSSM

gluinos and neutralinos are Dirac
additional pair of charginos

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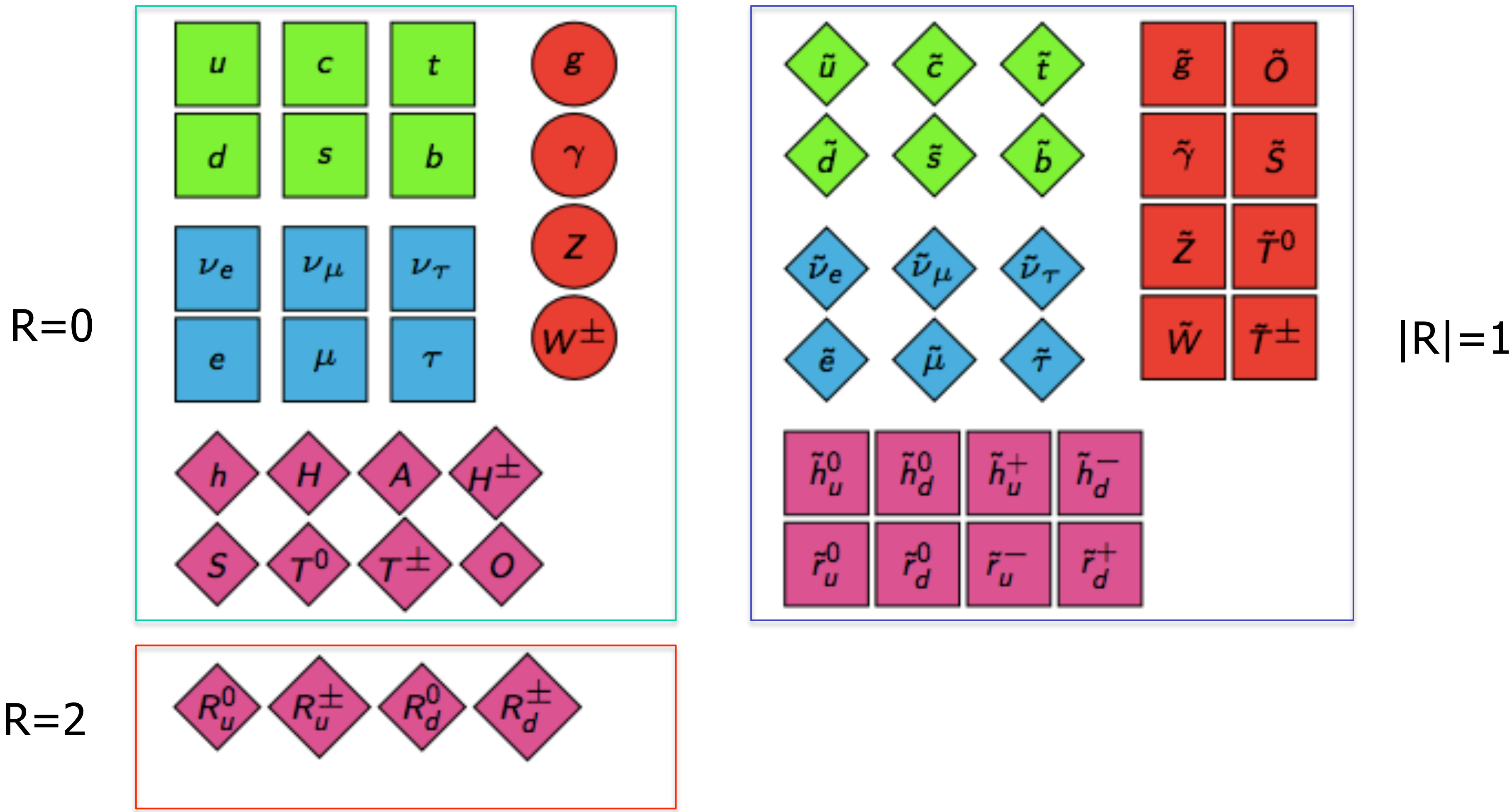
Physical fields:

matter, gauge and Higgs as in MSSM

gluinos and neutralinos are Dirac
additional pair of charginos

gauge-adjoint scalars (e.g. sgluons)
and R-Higgs bosons

MRSSM


R=0
u c t d s b
g γ Z W±
νe νμ ντ e μ τ
h H A H±
S T0 T± O
R=2
R0u R±u R0d R±d
|R|=1
ũ c̃ t̃ d̃ s̃ b̃
ν̃e ν̃μ ν̃τ ẽ μ̃ τ̃
g̃ Õ γ̃ S̃ Z̃ T̃0 W̃ T̃±
h̃0u h̃0d h̃+u h̃−d
r̃0u r̃0d r̃−u r̃+d

MRSSM Lagrangian

Superpotential

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

soft SUSY breaking terms

$$\begin{aligned} V_{SB}^{EW} =& B_\mu (H_d^- H_u^+ - H_d^0 H_u^0) + \text{h.c.} \\ &+ m_{H_d}^2 (|H_d^0|^2 + |H_d^-|^2) + m_{H_u}^2 (|H_u^0|^2 + |H_u^+|^2) \\ &+ m_{R_d}^2 (|R_d^0|^2 + |R_d^+|^2) + m_{R_u}^2 |R_u^0|^2 + m_{R_u}^2 |R_d^-|^2 \\ &+ m_S^2 |S|^2 + m_T^2 |T^0|^2 + m_T^2 |T^-|^2 + m_T^2 |T^+|^2 + m_O^2 |O|^2 \\ &+ \tilde{d}_{L,i}^* m_{q,ij}^2 \tilde{d}_{L,j} + \tilde{d}_{R,i}^* m_{d,ij}^2 \tilde{d}_{R,j} + \tilde{u}_{L,i}^* m_{q,ij}^2 \tilde{u}_{L,j} + \tilde{u}_{R,i}^* m_{u,ij}^2 \tilde{u}_{R,j} \\ &+ \tilde{e}_{L,i}^* m_{l,ij}^2 \tilde{e}_{L,j} + \tilde{e}_{R,i}^* m_{e,ij}^2 \tilde{e}_{R,j} + \tilde{\nu}_{L,i}^* m_{l,ij}^2 \tilde{\nu}_{L,j} \,. \end{aligned}$$

Mass spectrum calculations

- Take Standard Model input at Z mass scale
- Convert everything consistently to $\overline{DR}$
- Run to M_{SUSY}
- Take MRSSM input parameters and calculate one-loop corrected masses
- Add further corrections to Higgs mass
- Tools: `SARAH`, `SPheno`,`FlexibleSUSY`,
- Automatizing for such a model complicated, many cross checks required

Philip Diessner, JK, Wojciech Kotlarski, Dominik Steckinger

JHEP 1412 (2014) 124, Adv. HEP (2015) 760729, JHEP 1603 (2016) 007,

MRSSM confronting experiment

Can the MRSSM accomodate the Higgs mass, EWPO and LHC constraints?

First option: 125 GeV Higgs – the lightest state

Higgs boson mass

- In SM Higgs boson mass is a free parameter
- In SUSY it is prediction of SUSY parameters as quartic coupling connected to gauge couplings
- Experimental value: 125.1 ± 0.3 GeV

In MRSSM the lightest Higgs at tree level:

$$m_h^2 < m_Z^2 \cos^2 2\beta - v^2 \left(\frac{\left(g_1 M_B^D + \sqrt{2}\lambda\mu\right)^2}{4(M_B^D)^2 + m_S^2} + \frac{\left(g_2 M_W^D + \Lambda\mu\right)^2}{4(M_W^D)^2 + m_T^2} \right) \cos^2 2\beta$$

➡ always lower than in the MSSM due to mixing with S and T

Higgs sector at one-loop level and beyond

Lightest Higgs and PO observables

Getting 125 GeV Higgs and PO not obvious because:

- mixing with other states lowers the tree level mass
  needs even larger radiative corrections than in MSSM
- no LR stop mixing – an important MSSM mechanism to rise
  the Higgs mass is not present
- the vev of the EW triplet contributes to the rho parameter at tree-level

$$m_Z^2 = \frac{g_1^2 + g_2^2}{4} v^2 \,, \qquad m_W^2 = \frac{g_2^2}{4} v^2 + g_2^2 v_T^2 \,, \qquad \hat{\rho}_{\rm tree} = 1 + \frac{4 v_T^2}{v^2}$$

- the W mass (and other PO) affected by loops
- LHC and flavor constraints

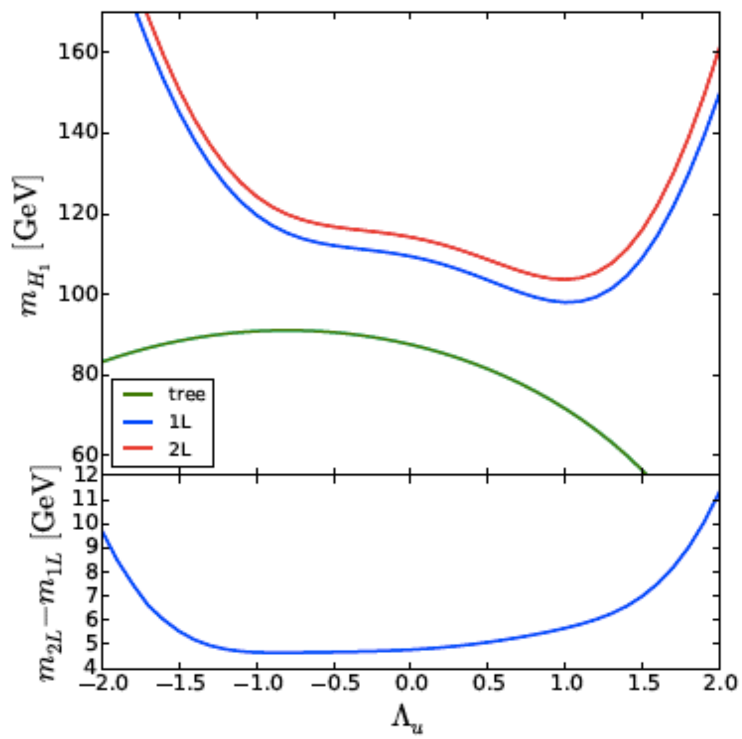
Lightest Higgs

New Yukawa-like couplings

$$\lambda_d \hat{H}_d \hat{R}_d \hat{S} + \lambda_u \hat{H}_u \hat{R}_u \hat{S} + \Lambda_d \hat{H}_d \hat{T} \hat{R}_d + \Lambda_u \hat{H}_u \hat{T} \hat{R}_u$$

$$\Delta m^2_{H_1,\mathrm{eff.pot},\lambda} = \frac{2v^2}{16\pi^2}\left[\frac{\lambda^4}{2}\left(\log\frac{m^2_{R_u}}{(M^D_B)^2} + \log\frac{m^2_S}{(M^D_B)^2}\right) + \frac{5\Lambda^4}{8}\left(\log\frac{m^2_{R_u}}{(M^D_W)^2} + \log\frac{m^2_T}{(M^D_W)^2}\right)\right]$$

Lightest Higgs



- 125 GeV Higgs for $\Lambda, \lambda \sim -1$

  without stop mixing

- light stops possible
- dominant two-loop ~ 5 GeV

W mass – full one-loop level

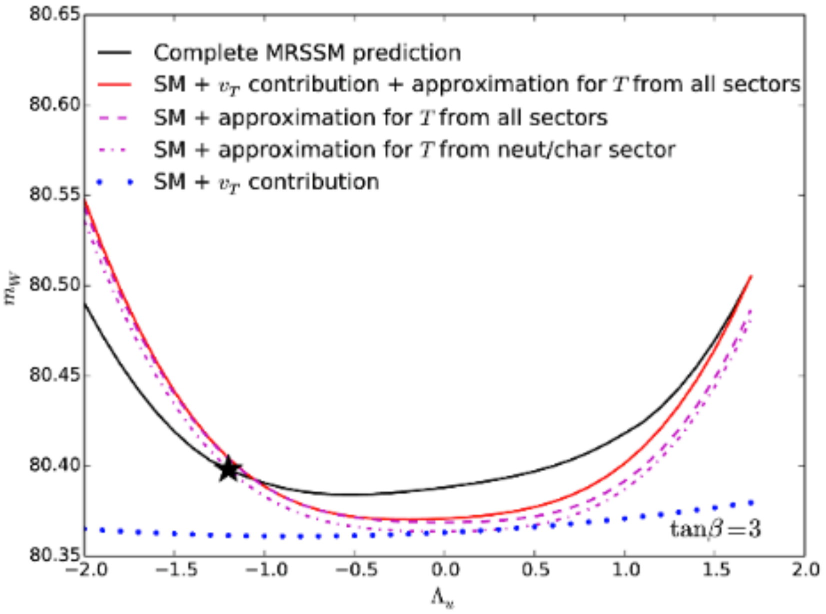
Beyond tree-level $$\frac{G_\mu}{\sqrt{2}} = \frac{\pi\hat{\alpha}}{2\hat{s}_W^2 m_W^2}\frac{1}{1-\Delta\hat{r}_W}$$

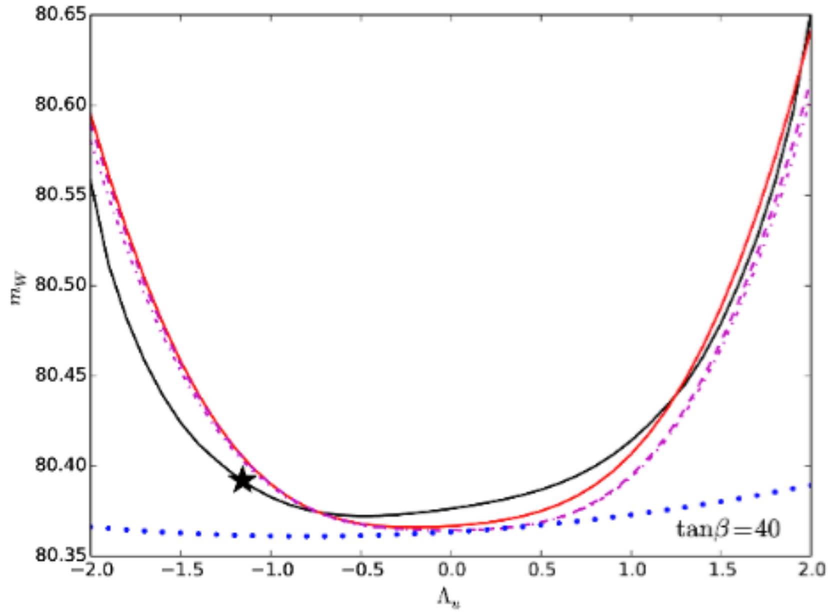
we get the master formula of Degrassi, Franchiotti, Sirlin (1990)

$$m_W^2 = \frac{1}{2}m_Z^2\hat{\rho}\left[1+\sqrt{1-\frac{4\pi\hat{\alpha}}{\sqrt{2}G_\mu m_Z^2\hat{\rho}(1-\Delta\hat{r}_W)}}\right]$$

need to calculate $\hat{\alpha}$, $\hat{\rho}$, and $\Delta\hat{r}_W$ at one-loop level

W mass – full one-loop level





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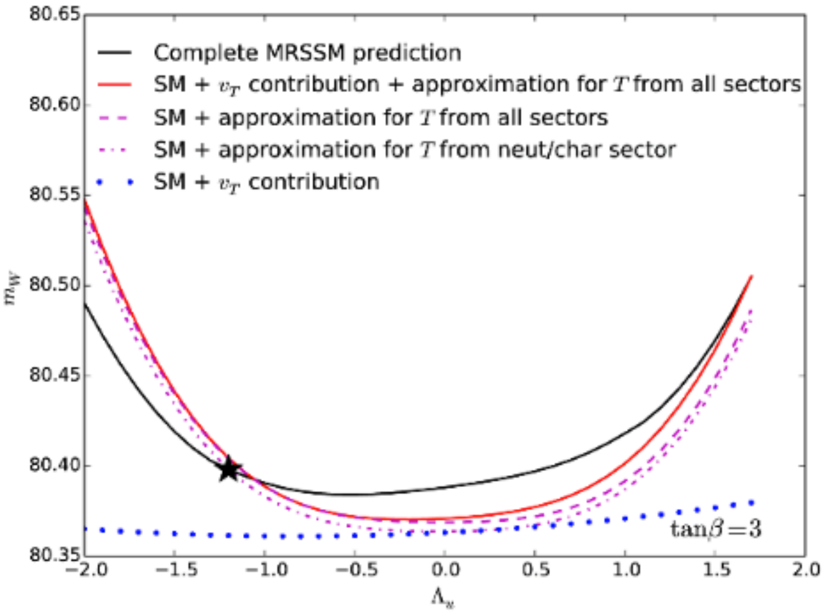

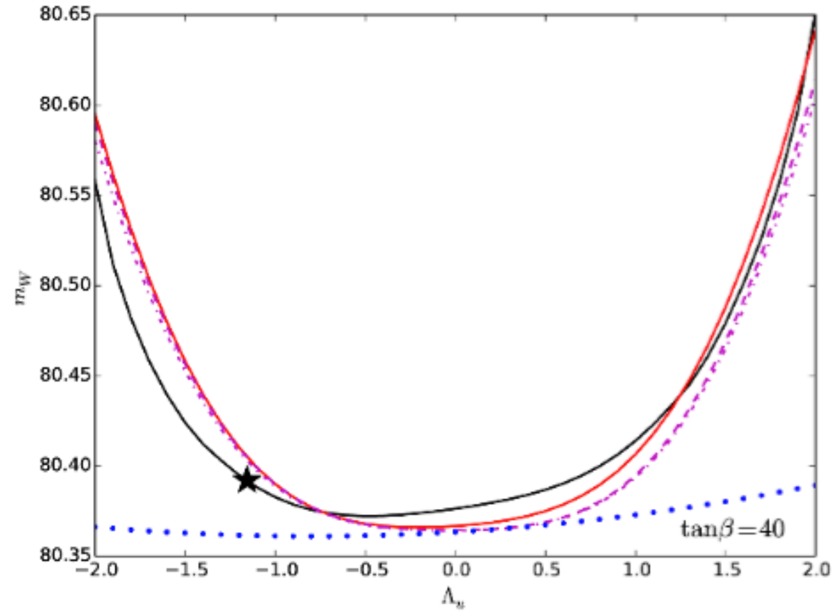

Benchmarks:

$$\tan\beta = 3, 10, 40$$

	BMP1	BMP2	BMP3
m_{H_1}	125.3 GeV	125.1 GeV	125.1 GeV
m_W	80.399 GeV	80.385 GeV	80.393 GeV
HiggsBounds's obsratio	0.61	0.61	0.63
HiggsSignals's p-value	0.42	0.40	0.40
S	0.0097	0.0092	0.0032
T	0.090	0.091	0.085
U	0.00067	0.00065	0.0010
Vevacious	✓	✓	✓
selected b physics observables	✓	✓	✓

MRSSM confronting experiment

Can the MRSSM accomodate the Higgs mass, EWPO and LHC constraints?

First option: 125 GeV Higgs – the lightest state

Diessner, JK, Kotlarski, Stockinger, JHEP 1412 (2014) 124

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Diessner, JK, Kotlarski, Stockinger, Adv. HEP (2015) 760729

Second option: 125 GeV Higgs – the next-to-lightest state

Diessner, JK, Kotlarski, Stockinger, JHEP 1603 (2016) 007

For the second-lightest, mixing with other fields pushes the tree-level mass upwards

Light singlet scenario

MRSSM with a light singlet

- In large $\tan\beta,\ M_A$ limit, the (ϕ_u, ϕ_S) mass submatrix

$$\mathcal{M}^{\phi}_{u,S} = \begin{pmatrix} m_Z^2 + \Delta m^2_{\rm rad} & v_u\left(\sqrt{2}\lambda_u \mu_u^{\rm eff,-} + g_1 M_B^D\right) \\ v_u\left(\sqrt{2}\lambda_u \mu_u^{\rm eff,-} + g_1 M_B^D\right) & 4(M_B^D)^2 + m_S^2 + \frac{\lambda_u^2 v_u^2}{2} \end{pmatrix}$$

$$\mu_i^{\rm eff,\pm} = \mu_i + \frac{\lambda_i v_S}{\sqrt{2}} \pm \frac{\Lambda_i v_T}{2}, \qquad i = u, d.$$

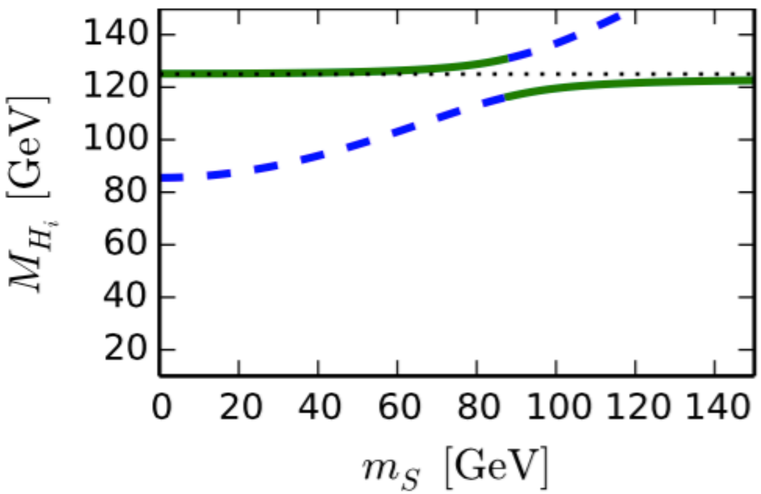
- to realise light singlet scenario

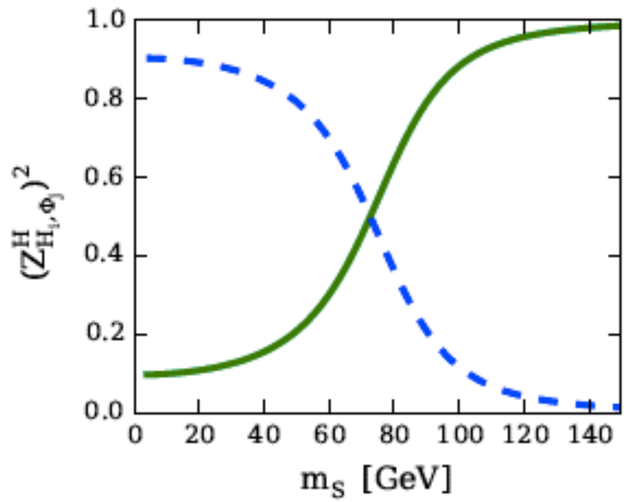
$$m_S, M_B^D < m_Z < \mu_u\,, \qquad |\lambda_u| \ll 1$$

- then the SM-like Higgs at tree level

$$m^2_{h,\rm tree} \approx m_Z^2 \cos^2 2\beta + v^2 \cos^2 2\beta \left(\frac{(g_1 M_B^D + \sqrt{2}\lambda\mu)^2}{|m_S^2 + 4(M_B^D)^2 - m_Z^2 \cos^2 2\beta|} \right)$$

MRSSM with a light singlet – one loop



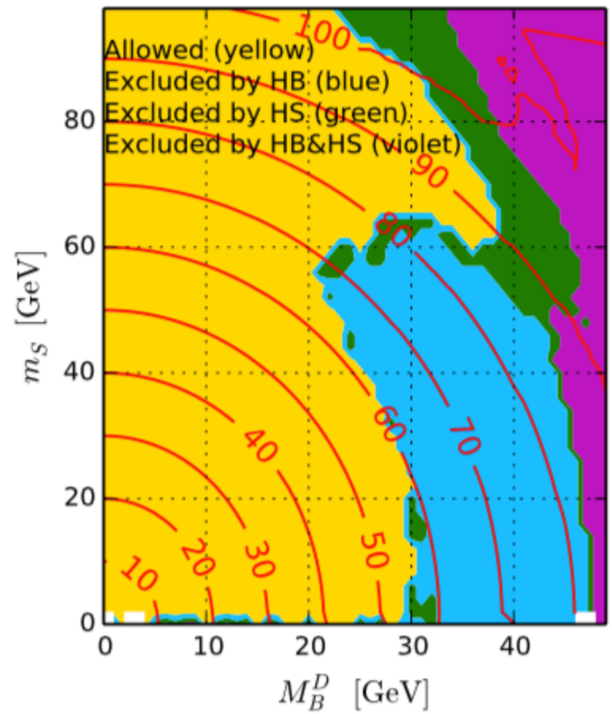


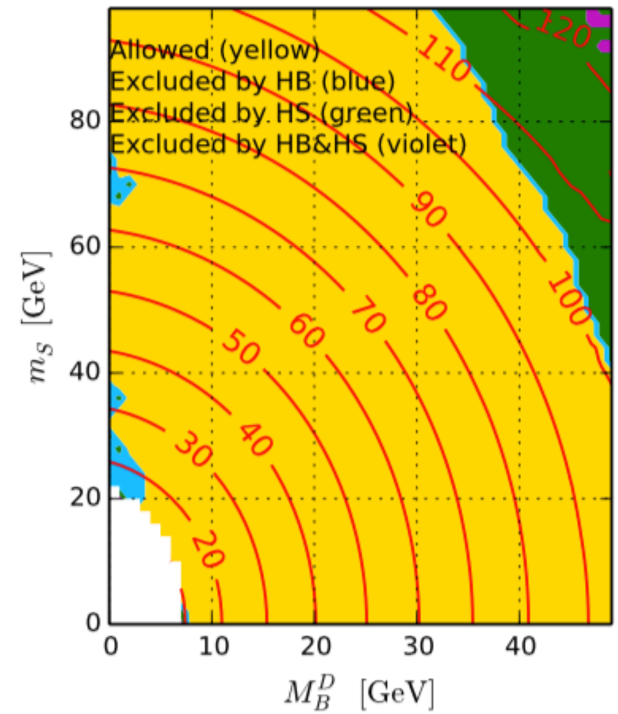
level crossing of two lightest Higgs bosons

$$m_{H_S} \approx \sqrt{m_S^2 + 4(M_B^D)^2}$$

MRSSM with a light singlet – one loop

LHC and PO constraints



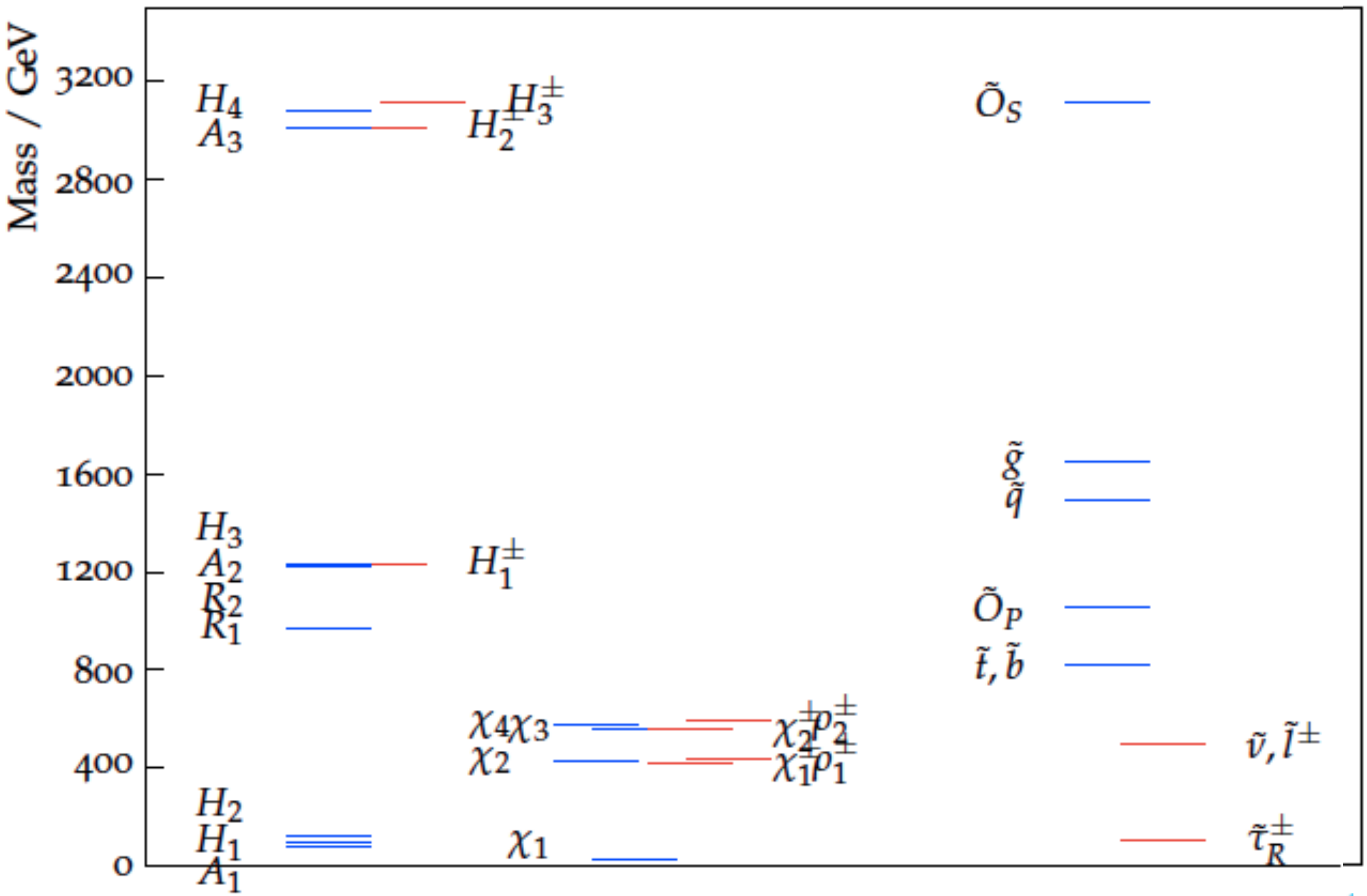


- $m_{H_S} \approx \sqrt{m_S^2 + 4(M_B^D)^2}$ (red)
- Upper limit on singlet mass ~ 110 GeV
- $M_B^D \lesssim 55$ GeV

➔ light fermion - LSP

	BMP4	BMP5	BMP6
m_{H_1}	100	94	95
m_{H_2}	125.8	125.5	125.8
HiggsSignals p-value	0.75	0.76	0.72
Allowed by HiggsBounds	✓	✓	✓
m_W	80.384	80.392	80.404

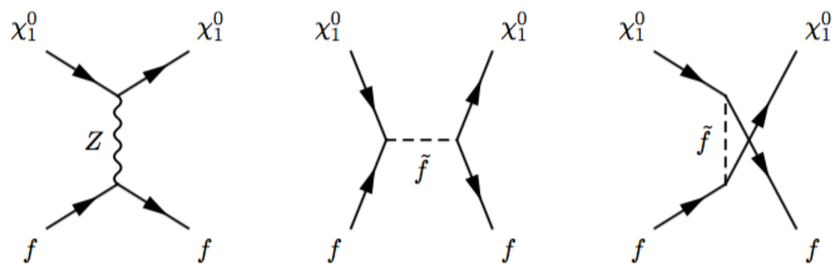
Light singlet – mass spectrum

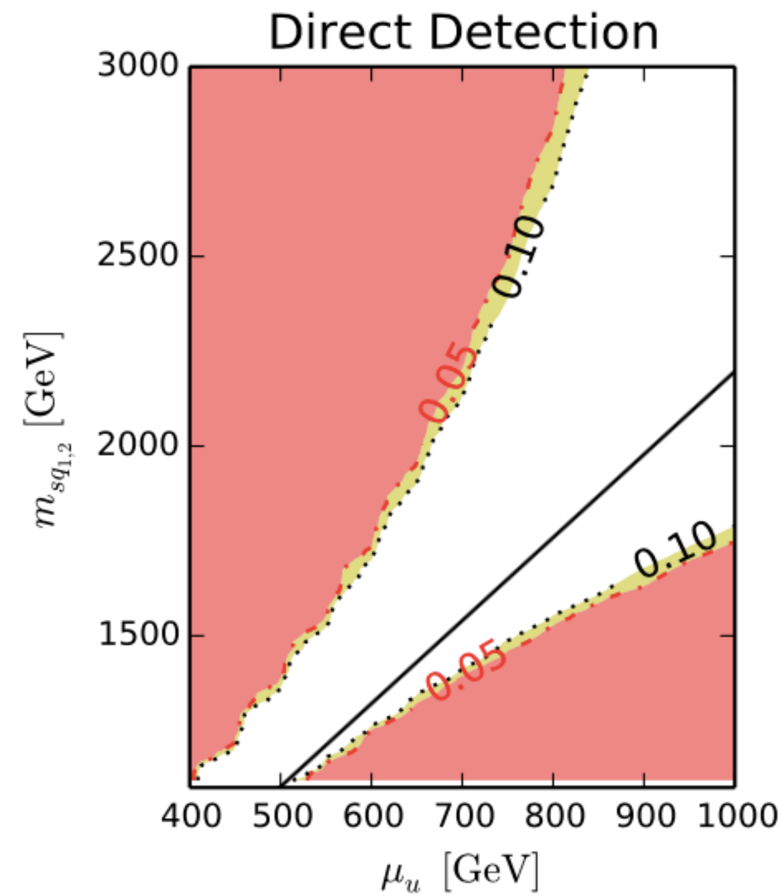


MRSSM dark matter – direct detection

Dirac LSP: cross section dominated by
vector part of Z and squark exchange

[Buckley, Hooper, Kumar 2013]



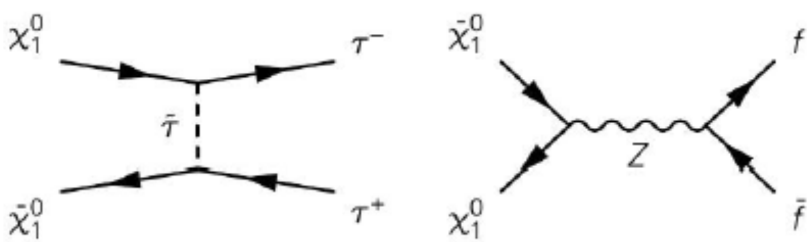


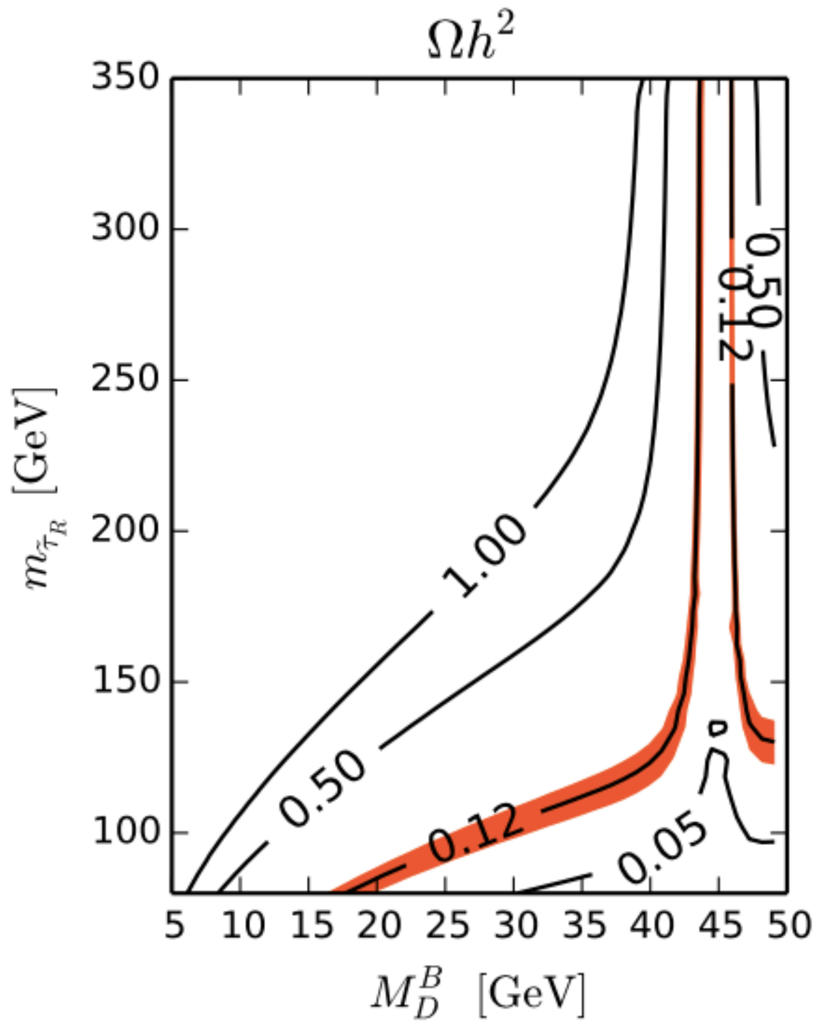
- Because of vector interaction naively TeV scale bounds
- But deconstructive interference **very important!**
- $m_{\tilde{q}} = \sqrt{\frac{7+11\frac{A-Z}{Z}}{3}}\mu_u \overset{Xe}{\approx} 2.2\mu_u$

MRSSM dark matter – relic density

Annihilation cross section large enough if:

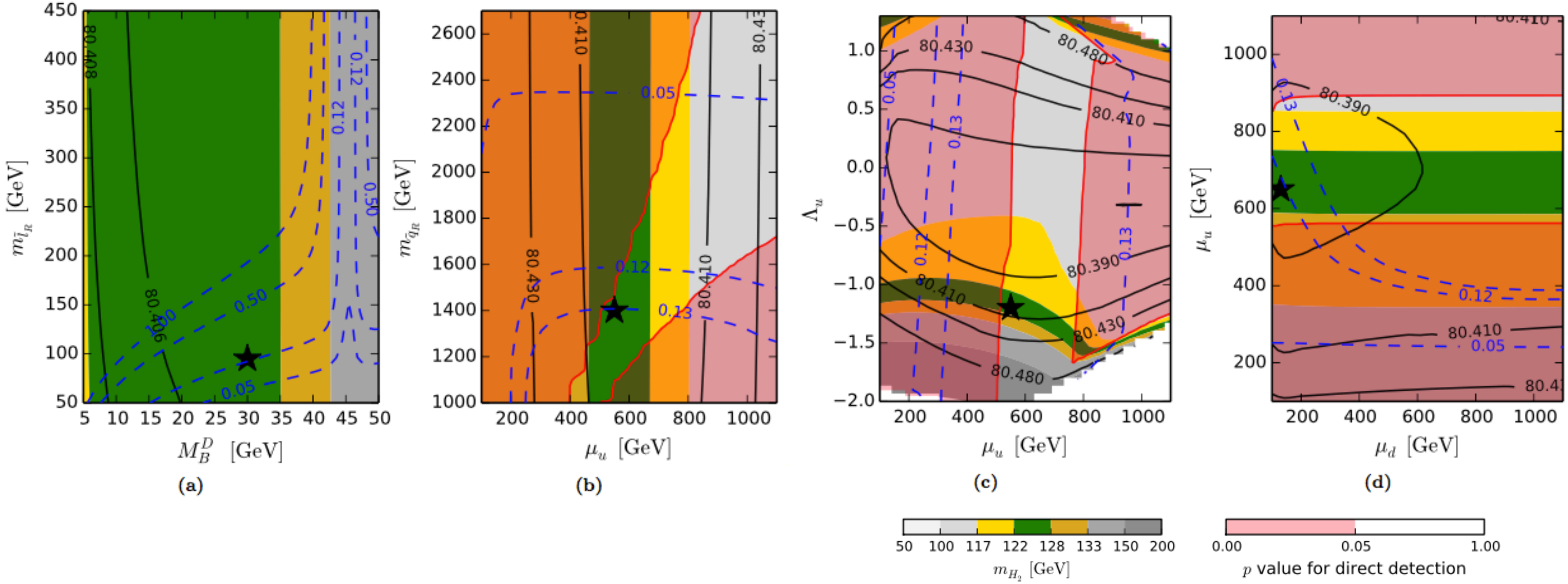
- resonant s-channel via Z exchange
- t channel stau exchange for light tau's





Used micrOMEGAs and LUXcalc

Light singlet: very predictive scenario



- ✓ 125 GeV Higgs fixess Λ_u
- ✓ If light singlet found at the LHC: constrains M_B^D and μ_u
- ✓ Fermionic superpartner is LSP
- ✓ DM constrains put redictions for squark masses
- ✓ Predictions for other electroweakinos

Summary

- Well motivated R-symmetric SUSY model
- SUSY flavor problem relaxed, Dirac gauginos and higgsinos
- Extended Higgs sector with unconventional phenomenology
- Viable benchmarks with
  - ~ 125 GeV Higgs boson mass
  - agreement with EWPO and flavor physics
  - stable vacuum
- Scenario with a light singlet is very predictive
  - consistent with LHC constraints
  - viable candidate for dark matter
  - some states light and could be seen at the LHC

Summary

- Well motivated R-symmetric SUSY model
- SUSY flavor problem relaxed
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- Viable benchmarks with
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  - stable vacuum
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  - consistent with LHC constraints
  - viable candidate for dark matter
  - some states light and could be seen at the LHC

Many things to do: rich phenomenology to explore

Backup

benchmarks:

one loop

	BMP1	BMP2	BMP3
$\tan\beta$	3	10	40
B_μ	500^2	300^2	200^2
$\lambda_d,\ \lambda_u$	$1.0, -0.8$	$1.1, -1.1$	$0.15, -0.15$
$\Lambda_d,\ \Lambda_u$	$-1.0, -1.2$	$-1.0, -1.0$	$-1.0, -1.15$
M_B^D	600	1000	250
$m_{R_u}^2$	2000^2	1000^2	1000^2
$\mu_d,\ \mu_u$		$400, 400$	
M_W^D		500	
M_O^D		1500	
$m_T^2,\ m_S^2,\ m_O^2$		$3000^2, 2000^2, 1000^2$	
$m_{Q;1,2}^2,\ m_{Q;3}^2$		$2500^2, 1000^2$	
$m_{D;1,2}^2,\ m_{D;3}^2$		$2500^2, 1000^2$	
$m_{U;1,2}^2,\ m_{U;3}^2$		$2500^2, 1000^2$	
$m_L^2,\ m_E^2$		1000^2	
$m_{R_d}^2$		700^2	
v_S	5.9	1.3	-0.14
v_T	-0.33	-0.19	-0.34
$m_{H_d}^2$	671^2	761^2	1158^2
$m_{H_u}^2$	-532^2	-544^2	-543^2
m_{H_1}	125.3 GeV	125.1 GeV	125.1 GeV
m_W	80.399 GeV	80.385 GeV	80.393 GeV
HiggsBounds's obsratio	0.61	0.61	0.63
HiggsSignals's p-value	0.42	0.40	0.40

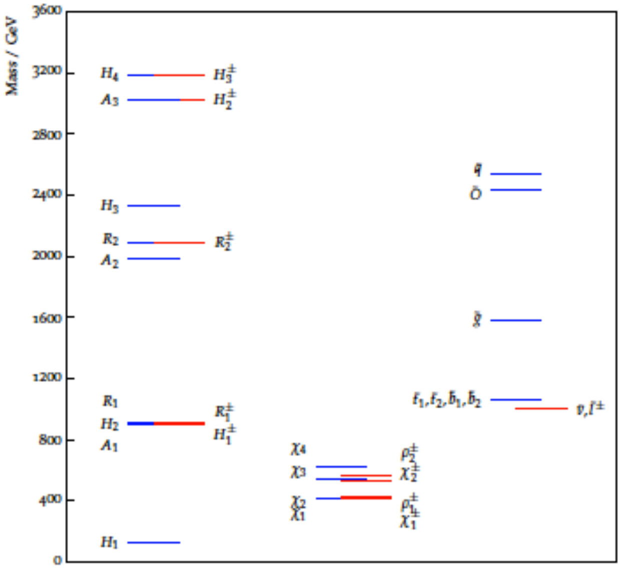
benchmarks:

one loop

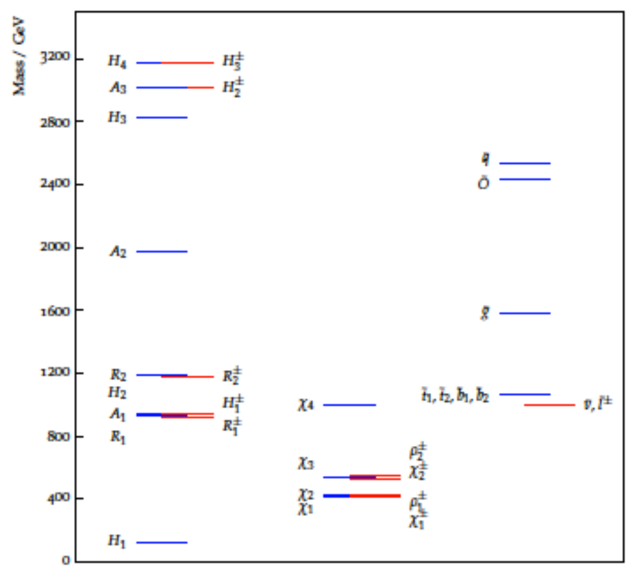
	BMP1	BMP2	BMP3	BMP1 (including two-loop corr.)	BMP2 (including two-loop corr.)	BMP3 (including two-loop corr.)
$\tan\beta$	3	10	40			
B_μ	500^2	300^2	200^2			
$\lambda_d,\ \lambda_u$	$1.0, -0.8$	$1.1, -1.1$	$0.15, -0.15$			
$\Lambda_d,\ \Lambda_u$	$-1.0, -1.2$	$-1.0, -1.0$	$-1.0, -1.15$	Λ_u reduces to -1.11	-0.85	-1.03
M_B^D	600	1000	250			
$m_{R_u}^2$	2000^2	1000^2	1000^2			
$\mu_d,\ \mu_u$		400, 400				
M_W^D		500				
M_O^D		1500				
$m_T^2,\ m_S^2,\ m_O^2$		$3000^2, 2000^2, 1000^2$				
$m_{Q;1,2}^2,\ m_{Q;3}^2$		$2500^2, 1000^2$				
$m_{D;1,2}^2,\ m_{D;3}^2$		$2500^2, 1000^2$				
$m_{U;1,2}^2,\ m_{U;3}^2$		$2500^2, 1000^2$				
$m_L^2,\ m_E^2$		1000^2				
$m_{R_d}^2$		700^2				
v_S	5.9	1.3	-0.14	5.2	1.01	-0.22
v_T	-0.33	-0.19	-0.34	-0.25	-0.02	-0.21
$m_{H_d}^2$	671^2	761^2	1158^2	674^2	764^2	1160^2
$m_{H_u}^2$	-532^2	-544^2	-543^2	-502^2	-512^2	-516^2
m_{H_1}	125.3 GeV	125.1 GeV	125.1 GeV	125.3 GeV	125.5 GeV	125.4 GeV
m_W	80.399 GeV	80.385 GeV	80.393 GeV	80.397 GeV	80.381 GeV	80.386 GeV
HiggsBounds's obsratio	0.61	0.61	0.63	0.61	0.65	0.87
HiggsSignals's p-value	0.42	0.40	0.40	0.72	0.66	0.72

benchmarks

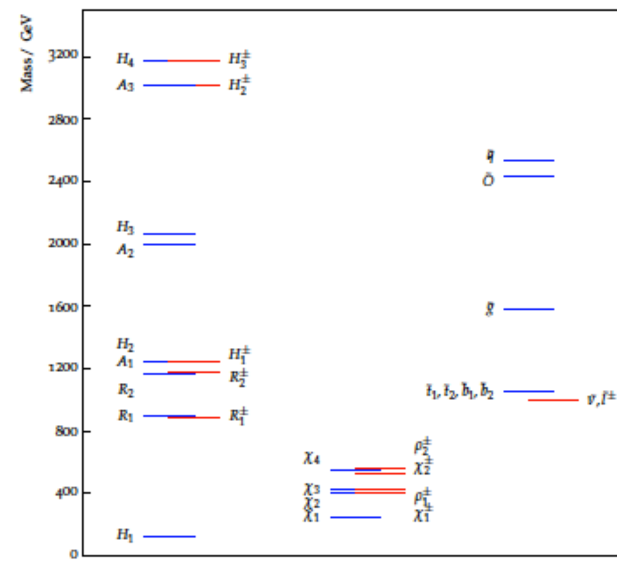
BMP1



BMP2



BMP3



benchmarks for light singlet scenario

	BMP4	BMP5	BMP6
$\tan\beta$	40	20	6
B_μ	200^2	200^2	500^2
$\lambda_d,\ \lambda_u$	$0.01, -0.01$	$0.0, -0.01$	$0.0, 0.0$
$\Lambda_d,\ \Lambda_u$	$-1, -1.2$	$-1, -1.15$	$-1, -1.2$
M^D_B	50	44	30
m^2_S	30^2	40^2	80^2
$m^2_{R_u},\ m^2_{R_d}$		$1000^2, 700^2$	
$\mu_d,\ \mu_u$	$130, 650$	$400, 550$	$550, 550$
M^D_W	600	500	400
M^D_O		1500	
$m^2_T,\ m^2_O$		$3000^2, 1000^2$	
$m^2_{Q;1,2},\ m^2_{Q;3}$	$1500^2, 700^2$	$1300^2, 700^2$	$1400^2, 700^2$
$m^2_{D;1,2},\ m^2_{D;3}$	$1500^2, 1000^2$	$1300^2, 1000^2$	$1400^2, 1000^2$
$m^2_{U;1,2},\ m^2_{U;3}$	$1500^2, 700^2$	$1300^2, 700^2$	$1400^2, 700^2$
$m^2_{L;1,2},\ m^2_{E;1,2}$	$800^2,\ 800^2$	$1000^2,\ 1000^2$	$500^2,\ 350^2$
$m^2_{L;3,3},\ m^2_{E;3,3}$	$800^2,\ 136^2$	$1000^2,\ 1000^2$	$500^2,\ 95^2$
m_{H_d}	1217^2	211^2	1042^2
m_{H_u}	$-(767^2)$	$-(207^2)$	$-(201)^2$
v_S	-64.9	-42.5	-56.1
v_T	-1.08	-1.2	-1.1

	χ_1^0	χ_2^0	χ_3^0	χ_4^0	$\chi_1^\pm$	$\chi_2^\pm$	$\rho_1^\pm$	$\rho_2^\pm$	$\tilde{\tau}_R$	$\tilde{\mu}_R$	$\tilde{e}_R$	$\tilde{\ell}_L$	m_{H_1}
BMP4	49.8	132	617	691	131	625	614	713	128	802	802	808	100
BMP5	43.9	401	519	589	409	524	519	610	1000	1001	1001	1005	94
BMP6	29.7	427	562	579	422	562	433	587	106	353	353	508	95

Table 5. Masses of the non-SM particles in the BMPs relevant for the LHC studies discussed here. All values given in GeV.