Higgs in the MRSSM

Jan Kalinowski

University of Warsaw

Norway grants

NATIONAL SCIENCE CENTRE POLAND

The Higgs sector – what we know

- In SM the EWSB achieved via Higgs mechanism in a most economical and simple way by introducing a single SU(2) scalar doublet

$$\mathcal{L}_{Higgs} = (\lambda_{ij}\bar{\psi}_i\psi_j\phi + h.c) + |D^\mu\phi|^2 - V(\phi)$$

- The ground state known since long time

$$G_\mu = \frac{1}{2v^2}$$

$$v = \langle\phi^\dagger\phi\rangle^{1/2} \sim 246\ \mathrm{GeV}$$

- July 4, 2012: Higgs particle discovered and its mass measured

- If it is really the SM Higgs, then the Higgs potential and its self-couplings are determined

$$V^{SM}(H) = \frac{1}{2}m_H^2 H^2 + \frac{m_H^2}{2v}H^3 + \frac{m_H^2}{2v^2}H^4$$

fixed

Are we there?

at the 10-20% level we tested

- couplings to 3rd gen. fermions: t, τ, b
- couplings to gauge bosons: W, Z, g, γ
- H^2 term in the Higgs potential
- spin 0

limited or no information on

- couplings to 2nd gen. fermions: c, s, μ
- H^3, H^4 couplings
- $HZ\gamma$ coupling

This is not good enough

Beyond the SM

Hundreds of different models but only a few basic concepts

- no elementary scalars: the Higgs as a bound state of fermions tied together by forces, called generically Technicolor
- Higgs could be much lighter than the high scale if it is a would-be-Goldstone boson of some new global symmetry
- extra spatial dimensions, bring the cutt-off scale down to ~ 1 TeV
- low-energy supersymmetry: scalars are related to fermions and thus enjoy chiral protection

all imply changes in the Higgs sector and
new states with masses ~ O(1 TeV)

SUSY – arguable the best proposition for BSM

In the simplest realisation each SM particle is paired with a sparticle that differs in spin by ½:

superfields in superspace $\{x^\mu, \theta, \bar{\theta}\}$

- fermions – sfermions
- Higgses – higgsinos

$$\hat{O} = O + \sqrt{2}\tilde{O}\theta + \theta\theta F_O$$

- gauge bosons – gauginos

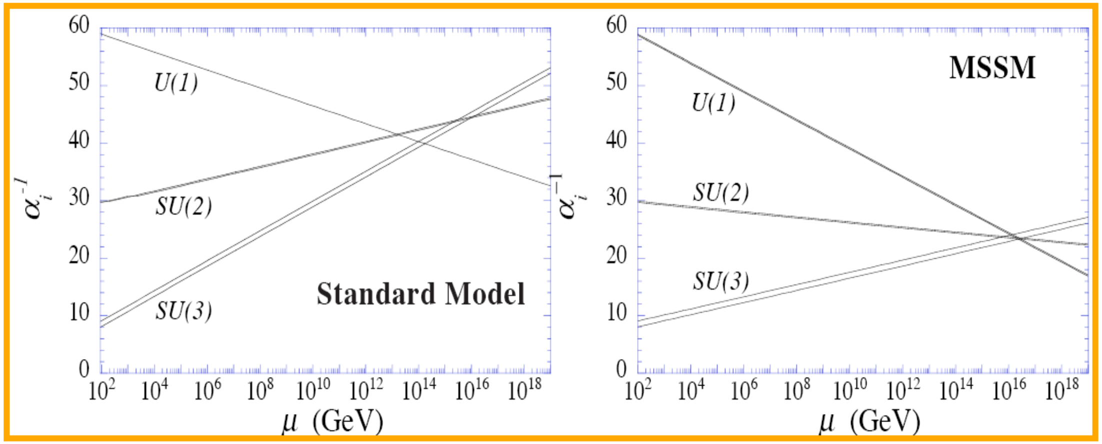
$$\hat{G}^\alpha \ni \lambda^\alpha + F^{\mu\nu}(\sigma_\mu \bar{\sigma}_\nu \theta)^\alpha + \ldots$$

neutral supersymmetric fermions are Majorana fermions

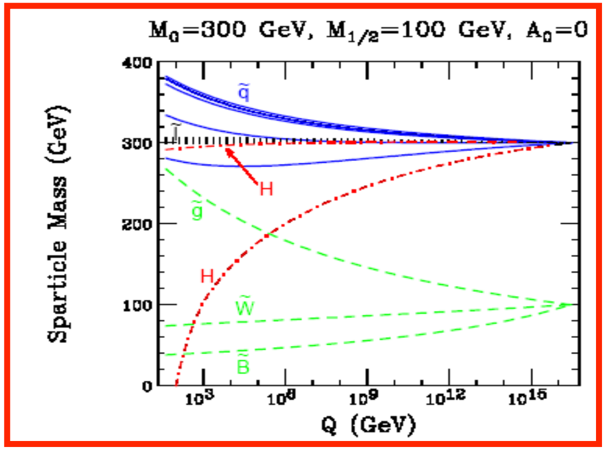
to be checked experimentally!

SUSY – has all in one package

- explains apparent gauge coupling unification



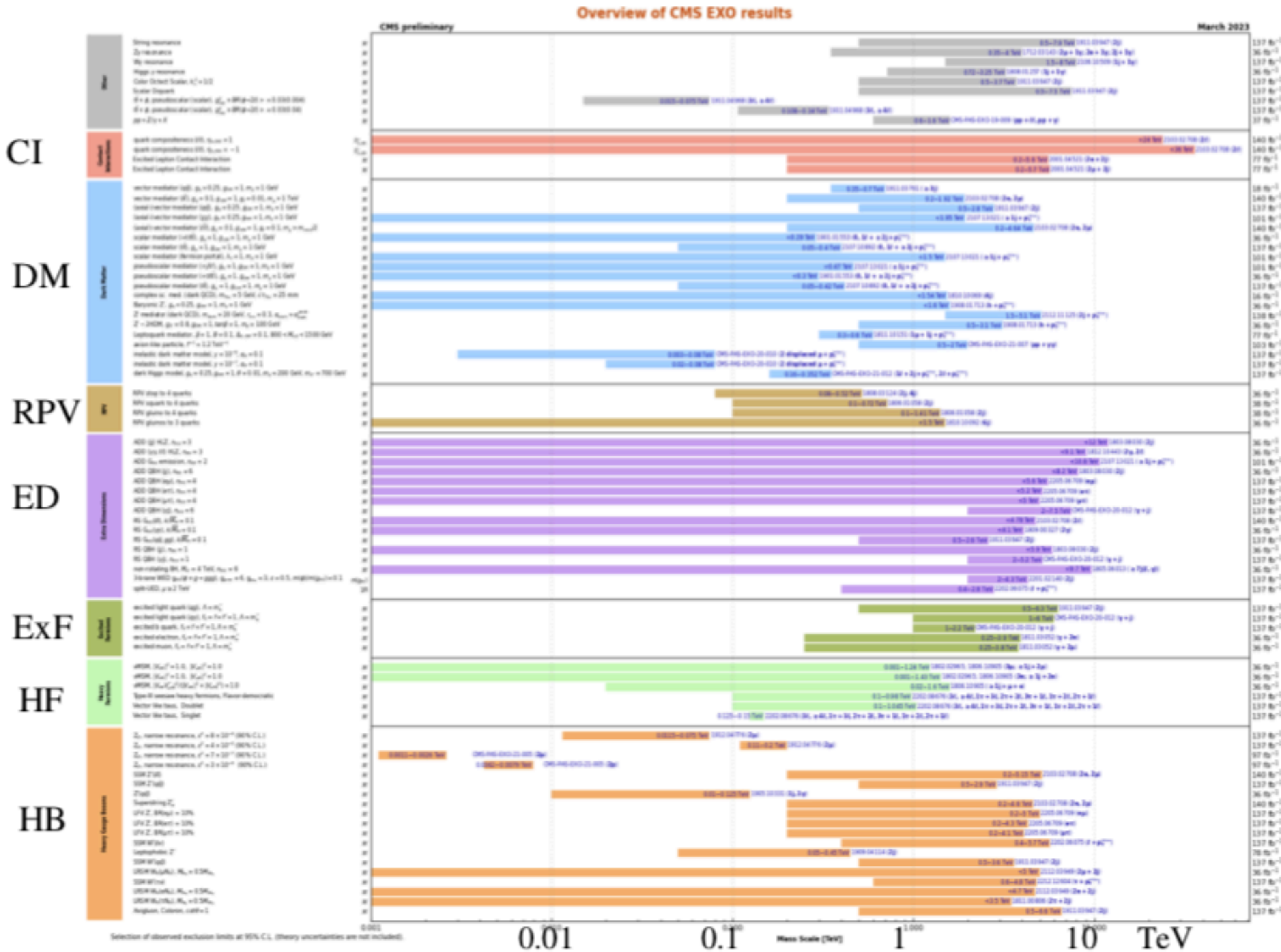
- accomodates heavy top quark and provides radiative electroweak symmetry breaking



- has a natural dark matter candidate
- is required by superstrings

➡ some SUSY states expected to show up at the LHC

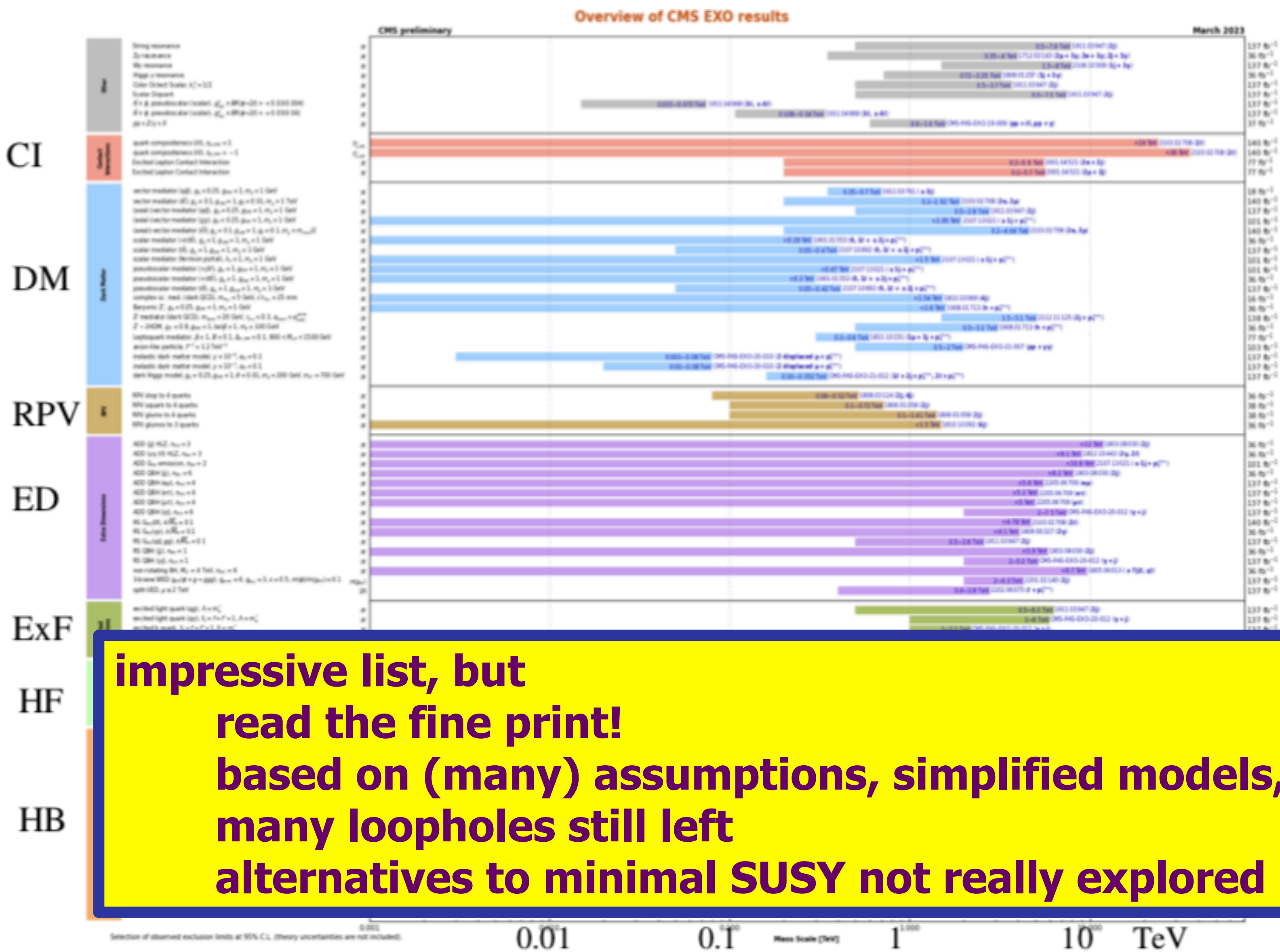
Depressing plots



In some searches, mass scales of ~ 5 TeV reached.

A. Lipniacka

Depressing plots



impressive list, but

- **read the fine print!**
- **based on (many) assumptions, simplified models,…**
- **many loopholes still left**
- **alternatives to minimal SUSY not really explored**

In some searches, mass scales of ~ 5 TeV reached.

A. Lipniacka

Question: how many SUSY do we need?

- N=0 (i.e. none)
- N=1

  with extra matter: NMSSM, THMSSM,...

  extra gauge factors: USSM, E_6SSM, BLSSM, ...
- $0<N<1$

  split SUSY, not-so split SUSY, natural SUSY, ...

  R-parity violating, ...
- $N>1$

  Dirac gauginos, R-symmetry, ...

Question: how many SUSY do we need?

- N=0 (i.e. none)
- N=1

  with extra matter: NMSSM, THMSSM,...

  extra gauge factors: USSM, E_6SSM, BLSSM, ...
- 0<N<1

  split SUSY, not-so split SUSY, natural SUSY, ...

  R-parity violating, ...
- N>1

  Dirac gauginos, R-symmetry, ...

I will discuss the R-symmetric supersymmetry

R-symmetry: surprisingly promising

- can accomodate 125 GeV SM-like Higgs
- can amelorate the MSSM flavor-violating problems
- can be consistent with EWPO
- has good dark matter candidates
- many light states still possible, some even below 150 GeV
- top squark can be relatively light
- has quite different LHC phenomenology – not really explored

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

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

[Chamseddine&Dreiner '95,..]

i.e. Grassmann coordinates have non-trivial R-charge

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

- For chiral superfield

$$\Phi(x,\theta) = \phi(x) + \sqrt{2}\theta\psi(x) + \theta\theta F(x)$$

$$e^{i\alpha R} \qquad e^{i\alpha R} \qquad e^{i\alpha}e^{i\alpha(R-1)}$$

➡ component fields have different R-charge

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

➡ kinetic terms are automatically R-symmetric

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

- Soft breaking terms ➡ must have R=0

R-symmetry and 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-symmetry and model building

terms allowed:

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

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

R-symmetry and model building

terms allowed:

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

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

terms forbidden:

- superpotential
  - mu-term $\mu \hat{H}_d \hat{H}_u$
  - L- and B-violation $\hat{L} \hat{Q} \hat{D}^c, \; \hat{H}_u \hat{L}$
- 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-symmetry and 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

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 superfields

  ➡ 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

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 Lagrangian

Superpotential

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

Soft SUSY breaking terms

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

important MRSSM features:

- mu-type terms for H- and R-Higgses
- Yukawa-like terms for R-Higgses and adjoint scalars
- no $B\mu$-like term for R-Higgses => do not develop vev's
- no mixing between H- and R-Higgses

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 Stoeckinger

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 at tree level

- 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:

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

"standard" $H_d - H_u$ mixture

singlet and triplet admixture

Need even more radiative corrections than in the MSSM

Lightest Higgs and precision 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

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

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

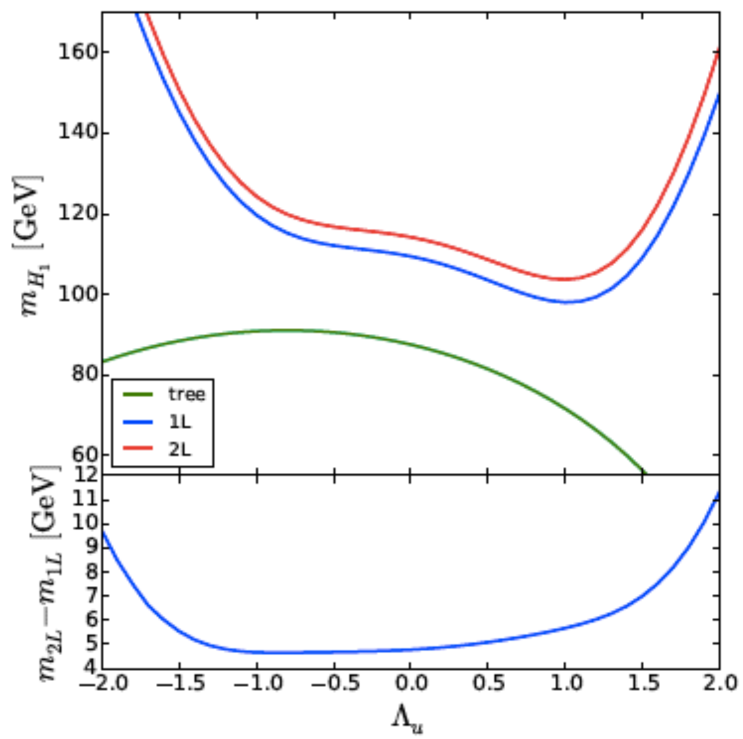
Lightest Higgs

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



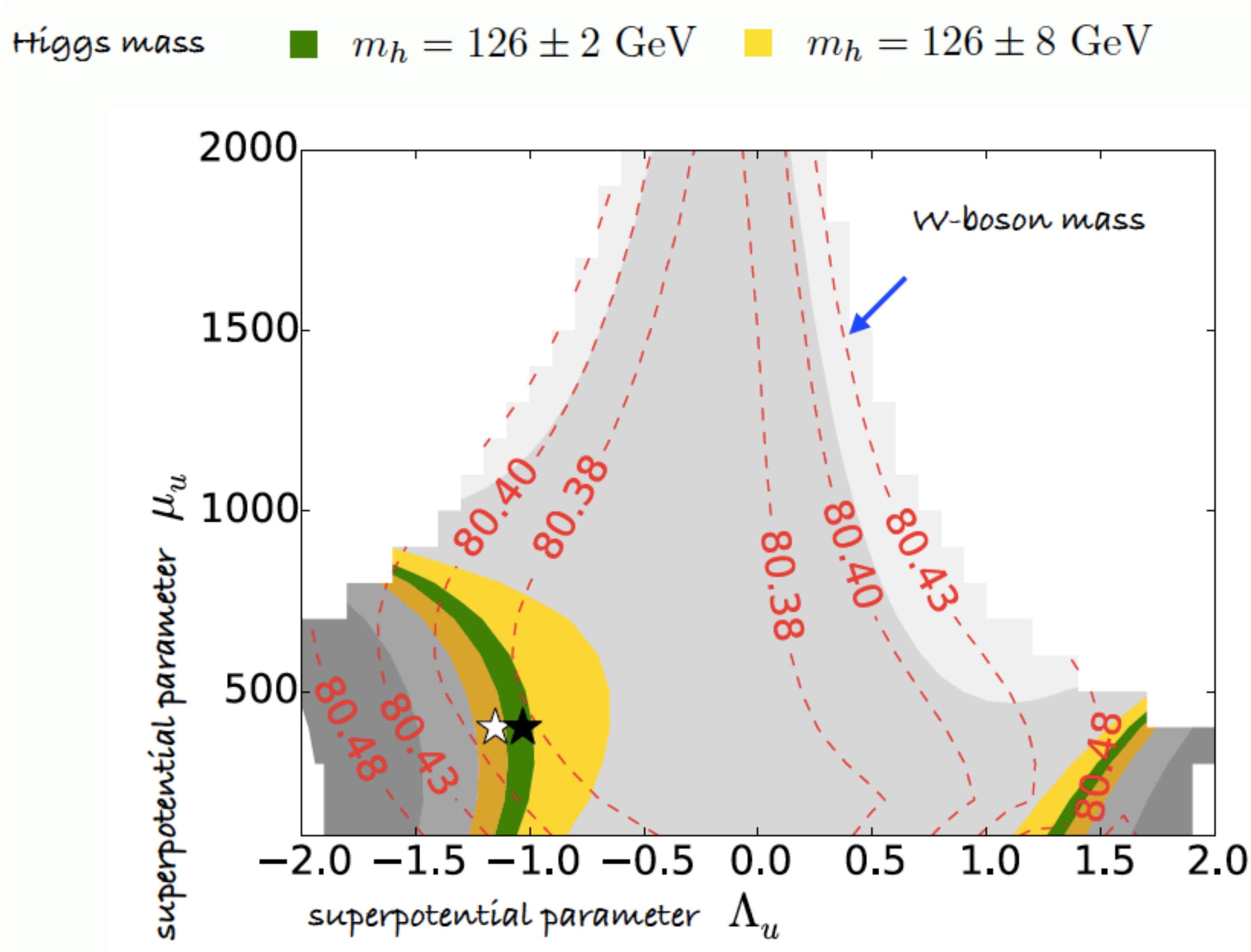
- 125 GeV Higgs for $\Lambda, \lambda \sim -1$

  without stop mixing

- light stops ~ 1 TeV possible

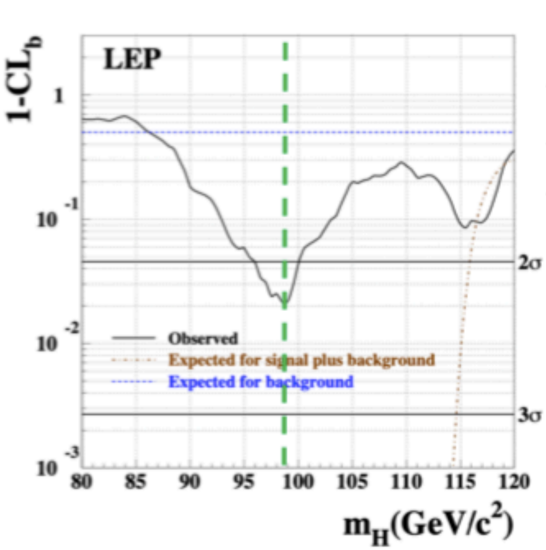
- dominant two-loop ~ 5 GeV from gluino and sgluon contributions

Higgs and W mass

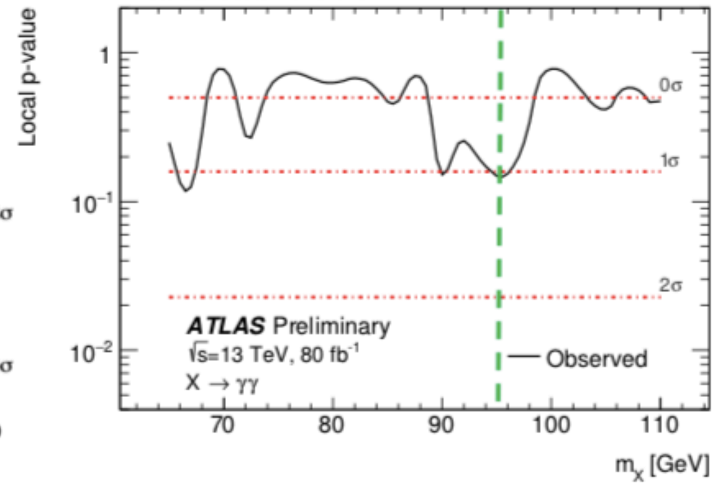


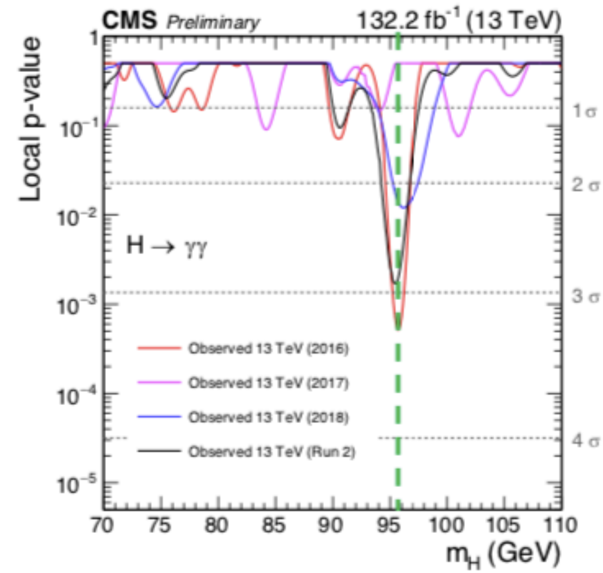
Experimental hints for a light state X-> $\gamma\gamma$

Phys.Lett.B565:61-75,2003



ATLAS-CONF-2018-025



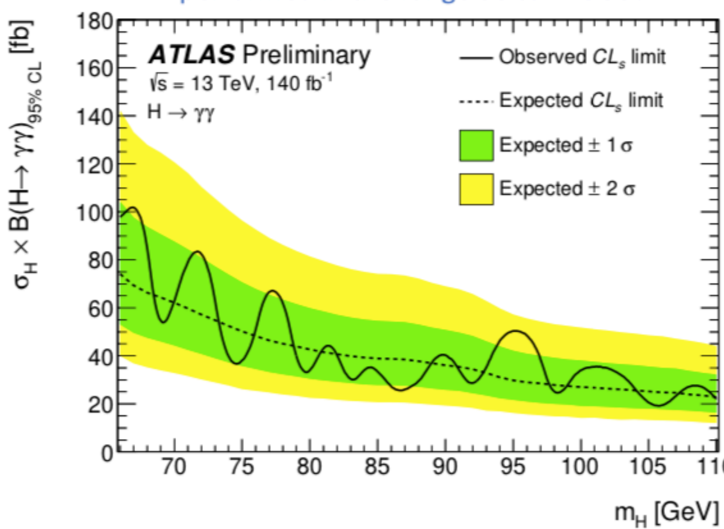


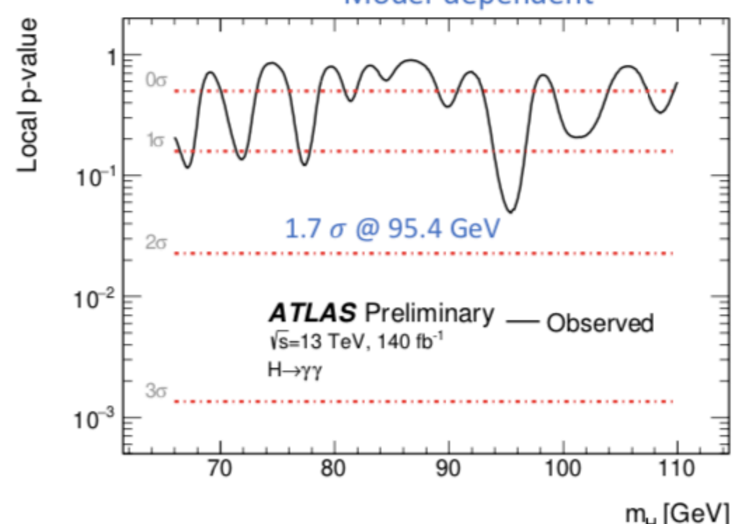
LHC Seminar | Chiara Arcangeletti | 7

A scan over different m_X hypotheses is performed in the range 66 to 110GeV.

Model-dependent

recent ATLAS update





Can MRSSM accomodate such a state?

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

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

JK, Kotlarski, work in progress

MRSSM with a light singlet

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

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

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

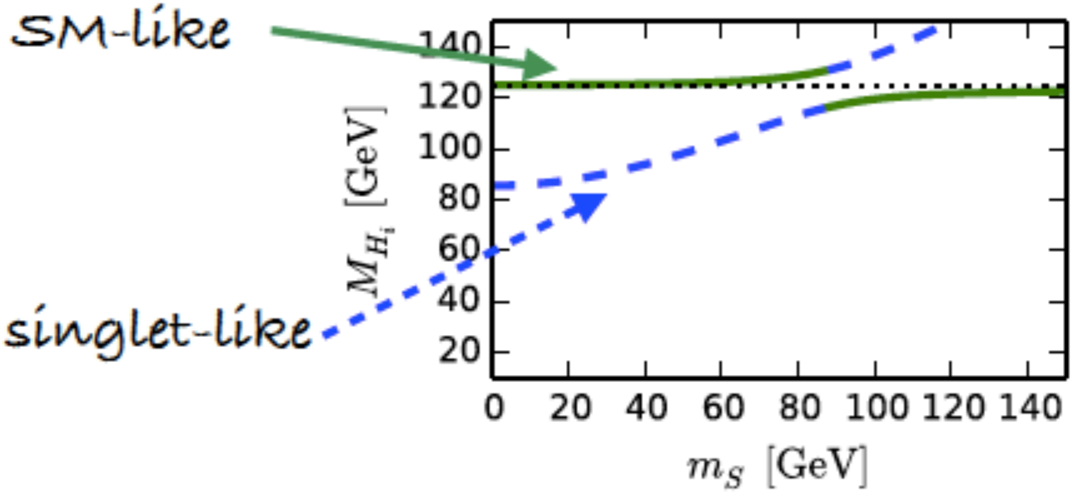
- to realise light singlet scenario

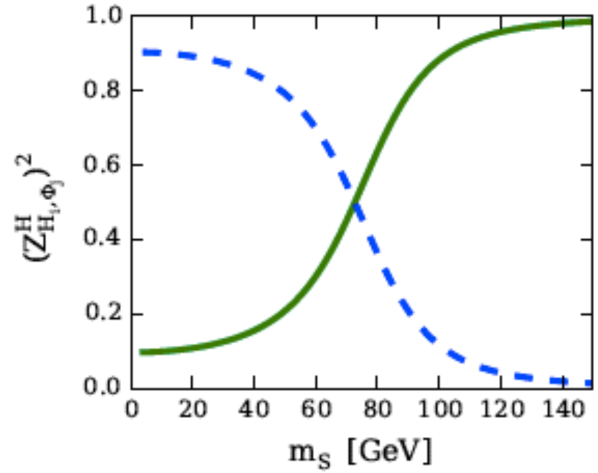
$$m_S, M_B^D < m_Z < \mu_u\,, \qquad |\lambda_u| \ll 1$$

- then the SM-like Higgs at tree level

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

MRSSM with a light singlet – one loop





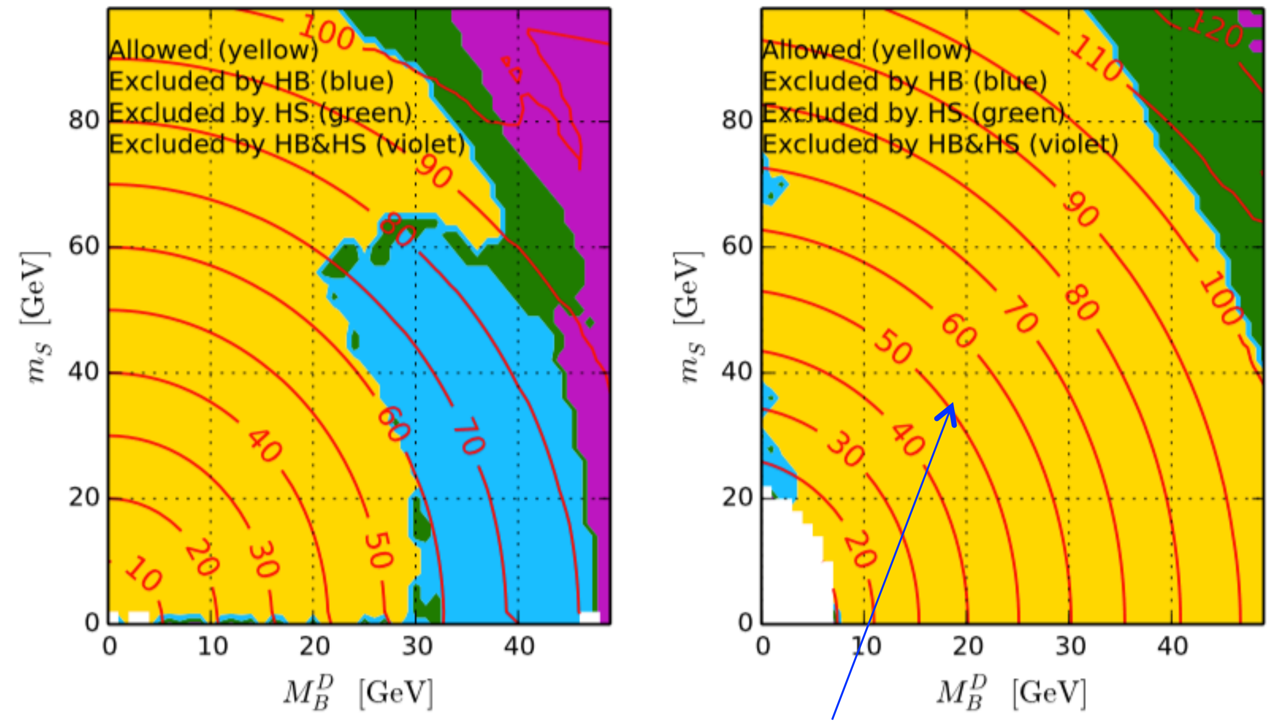
level crossing of two
lightest Higgs bosons

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

For the second-lightest SM-like Higgs, mixing with S and T pushes its tree-level mass upwards

MRSSM with a light singlet – one loop

LHC and PO constraints



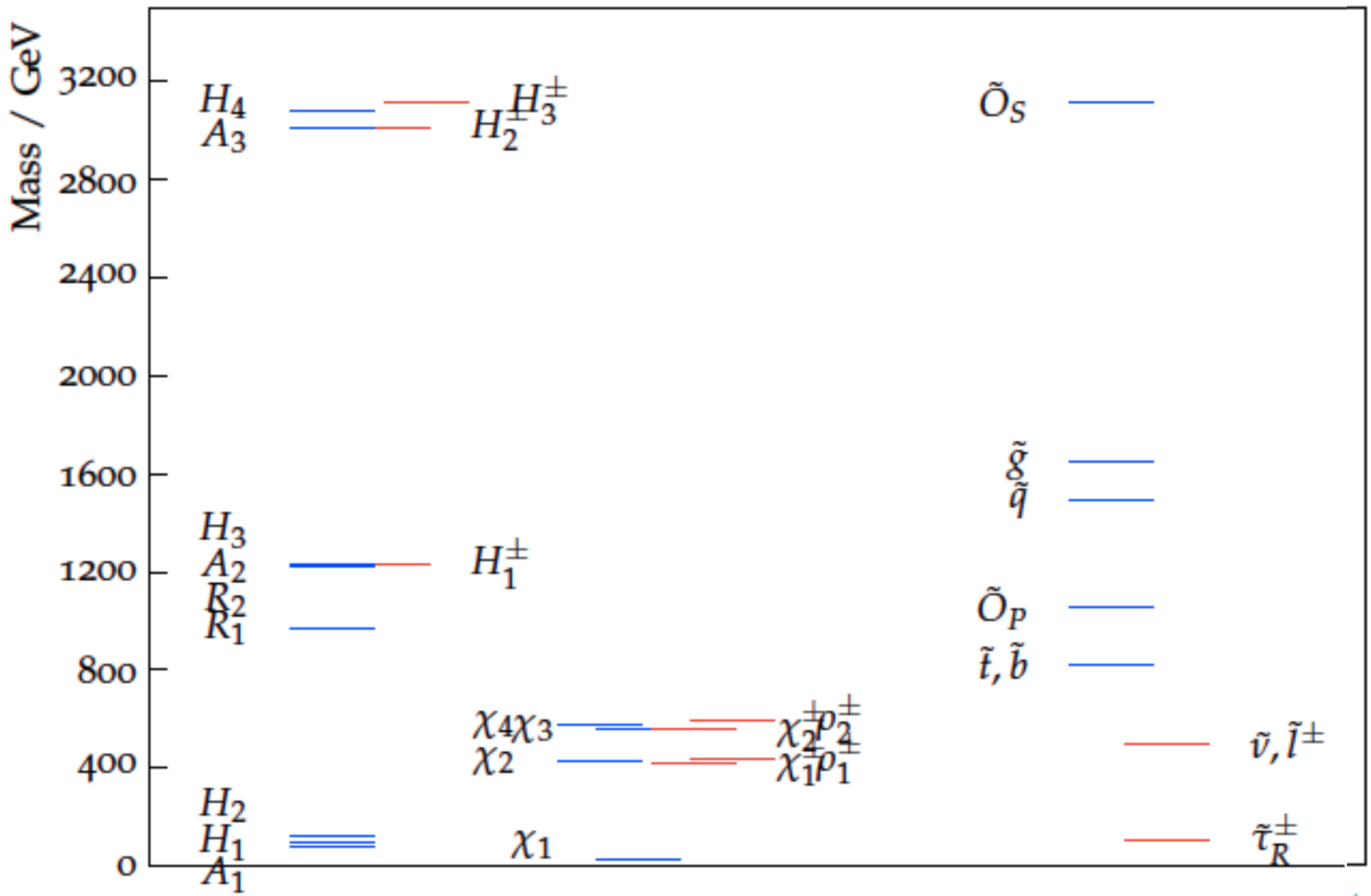
lightest Higgs mass

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

necessarily 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

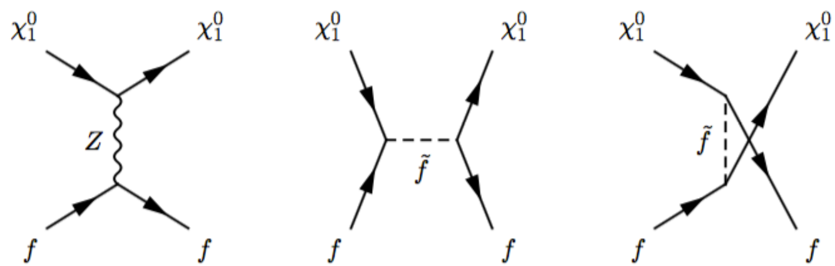
Light singlet – mass spectrum



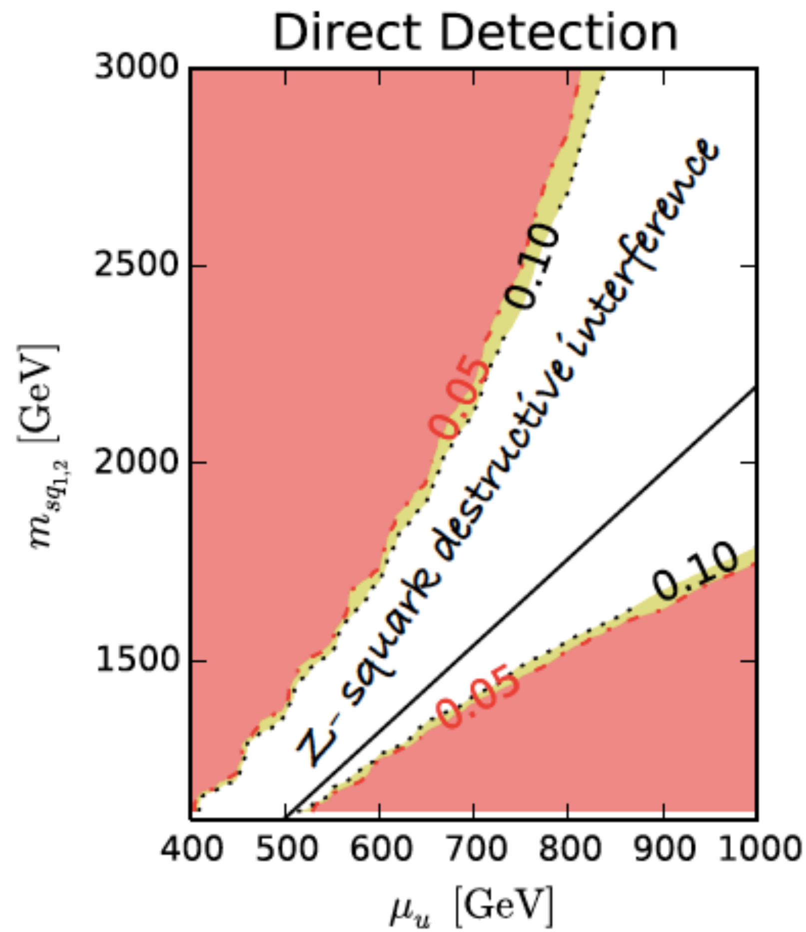
MRSSM dark matter – direct detection

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!**
- $m_{\tilde{q}} = \sqrt{\frac{7+11\frac{A-Z}{Z}}{3}}\mu_u \overset{\text{Xe}}{\approx} 2.2\mu_u$

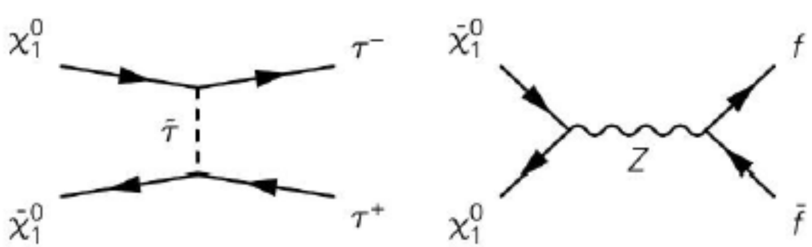


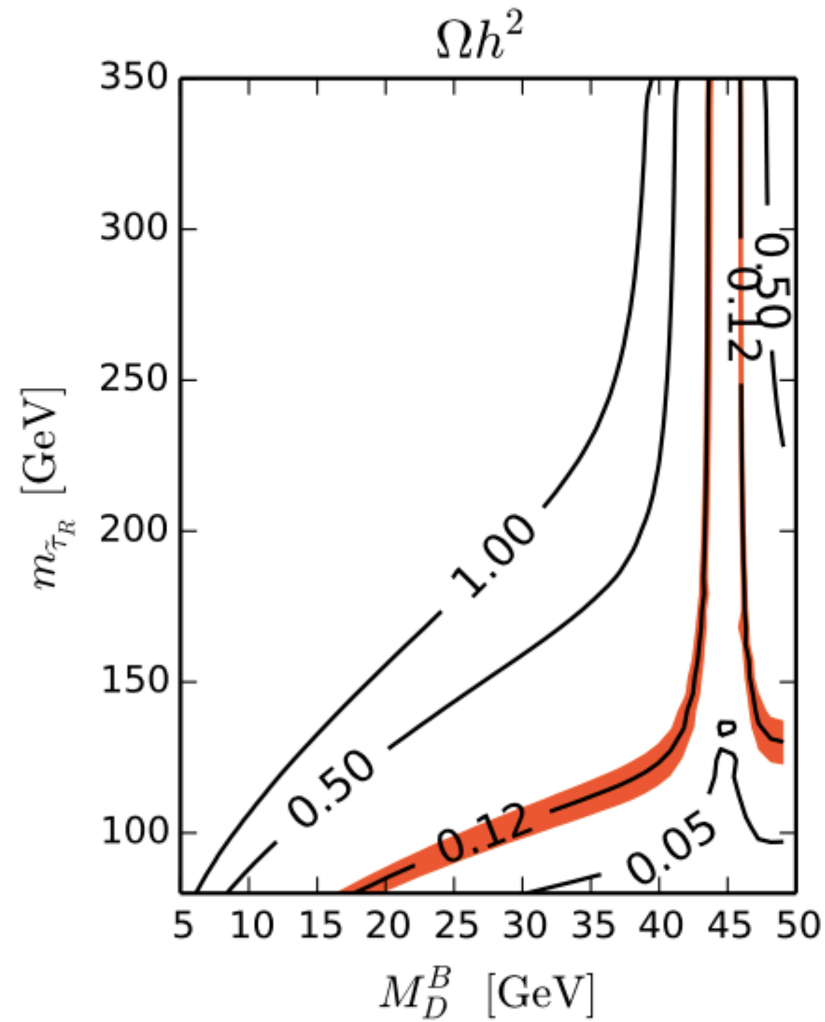
LUXCalc and micrOMEGAs checked with analytic estimates

MRSSM dark matter – relic density

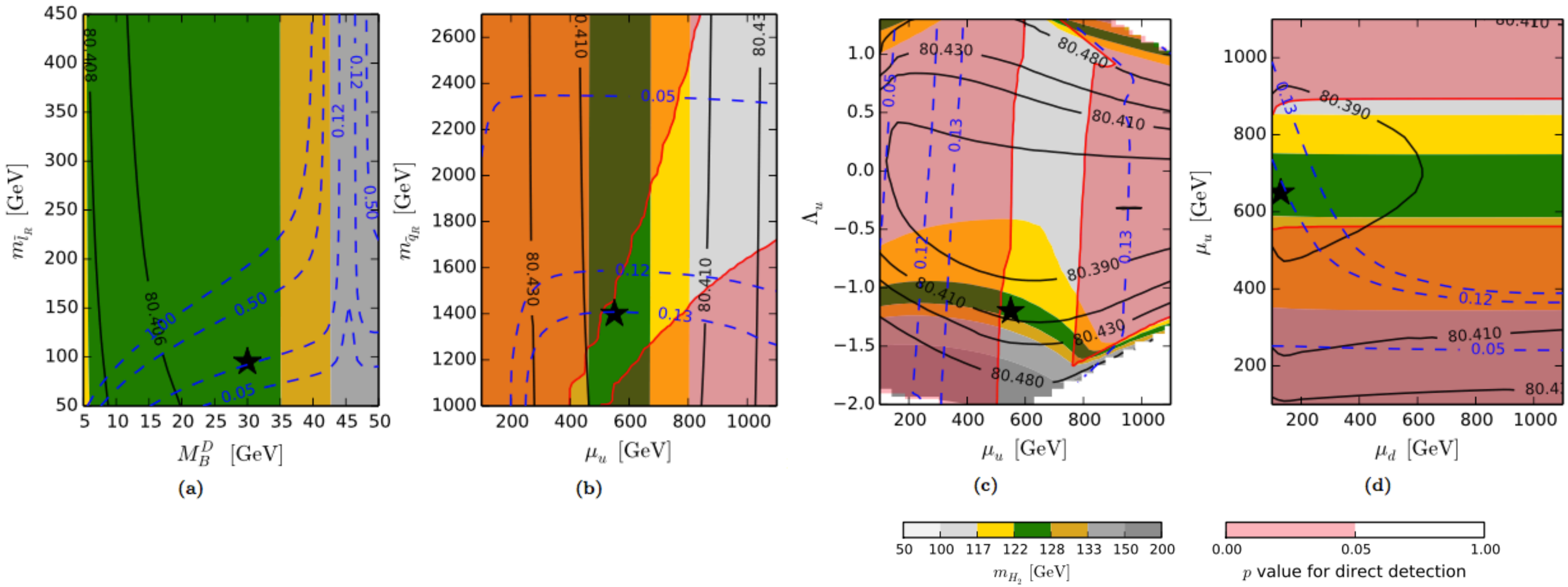
Annihilation cross section large enough if:

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





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 predictions for squark masses
- ✓ Predictions for other electroweakinos

Summary

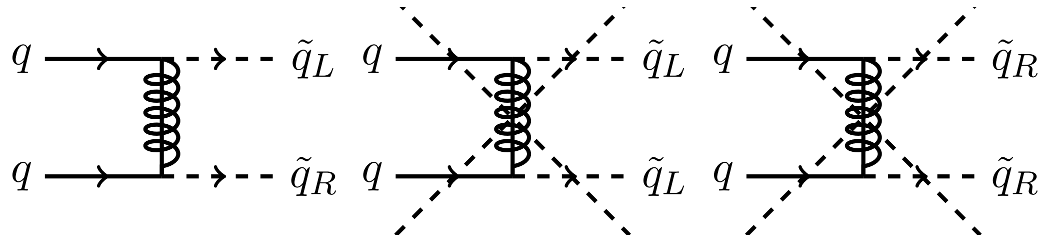
- Well motivated R-symmetric SUSY model
- SUSY flavor problem relaxed
- Extended Higgs sector with unconventional phenomenology
- Viable benchmarks with
  - ~ 125 GeV Higgs boson mass
  - agreement with EWPO and flavor physics
  - stable vacuum
- Scenario with a light singlet is very predictive
  - consistent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

- rich LHC phenomenology to explore – work in progress

extra slides

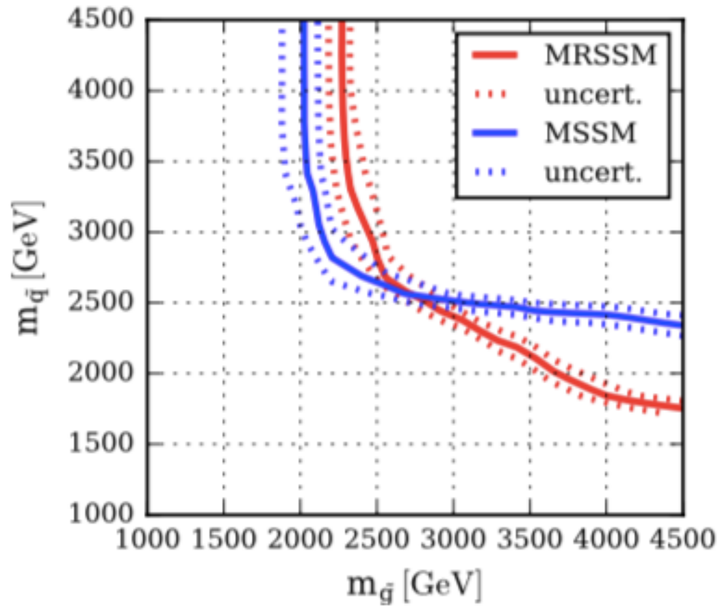
Gluinos and squarks

squark pair production smaller than in MSSM



gluino pair production ~ 2 x MSSM

- Limit derived with `Herwig` 7 and `CheckMate` 2
- ATLAS search for 0ℓ, 2-6 jets + E^T_{miss} , 36 fb^{-1} [1712.02332]
- Comparing MRSSM and MSSM
  - Stronger limits on gluino mass
  - Weaker for (first generations) squark masses



Diessner, JK, Kotlarski, Stoeckinger, JHEP 09 (2019) 120

MRSSM Lagrangian

Superpotential

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

Soft SUSY breaking terms

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

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_B^D	50	44	30
m_S^2	30^2	40^2	80^2
$m_{R_u}^2,\ m_{R_d}^2$		$1000^2, 700^2$	
$\mu_d,\ \mu_u$	$130, 650$	$400, 550$	$550, 550$
M_W^D	600	500	400
M_O^D		1500	
$m_T^2,\ m_O^2$		$3000^2, 1000^2$	
$m_{Q;1,2}^2,\ m_{Q;3}^2$	$1500^2, 700^2$	$1300^2, 700^2$	$1400^2, 700^2$
$m_{D;1,2}^2,\ m_{D;3}^2$	$1500^2, 1000^2$	$1300^2, 1000^2$	$1400^2, 1000^2$
$m_{U;1,2}^2,\ m_{U;3}^2$	$1500^2, 700^2$	$1300^2, 700^2$	$1400^2, 700^2$
$m_{L;1,2}^2,\ m_{E;1,2}^2$	$800^2,\ 800^2$	$1000^2,\ 1000^2$	$500^2,\ 350^2$
$m_{L;3,3}^2,\ m_{E;3,3}^2$	$800^2,\ 136^2$	$1000^2,\ 1000^2$	$500^2,\ 95^2$
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.

W mass – full one-loop level

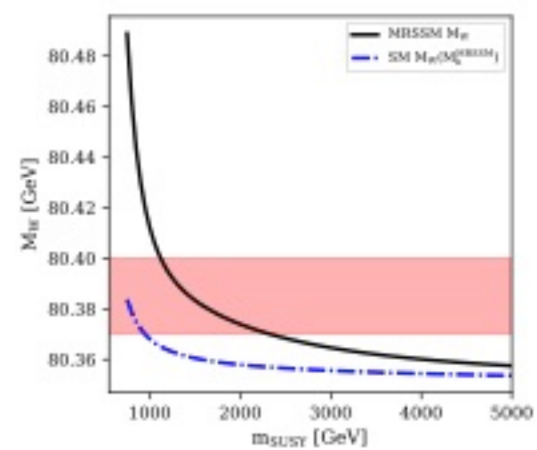
muon decay beyond tree-level $$\frac{G_\mu}{\sqrt{2}} = \frac{e^2}{8M_W^2 s_W^2}(1+\Delta r)$$

Precisely known $\alpha,\ M_Z,\ G_\mu$ can solve for W mass

$$M_W^2 = M_Z^2\left(\frac{1}{2}+\sqrt{\frac{1}{4}-\frac{\alpha\pi}{\sqrt{2}G_\mu M_Z^2}(1+\Delta r)}\right)$$

neglecting triplet vev

New calculation by Diessner and Weiglein



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 $((-1)^{3B+L+2S})$

For R-symmetry τ is arbitrary: conserved R-charges