55. Cracow School of Theoretical Physics

Particles and resonances of the Standard Model and beyond

June 20 - 28, 2015
Zakopane, Poland

SUSY with R-symmetry: confronting EWPO and LHC constraints

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Motivation

Fantastic first three years of LHC run 1 with plenty of data

- from the first $\pi \rightarrow \gamma\gamma$ reconstructed
  - to „rediscovery" of the SM
    - precise SM measurements
      - culminated with the discovery of a Higgs ~ 125 GeV

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A new era has begun

- already quite precise measurement of properties consistent with SM prediction within errors
- searches beyond the SM
- ultimately: understand the nature of EWSB

A great triumph of a weakly coupled SM

Although very successful, the SM is not the ultimate theory

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

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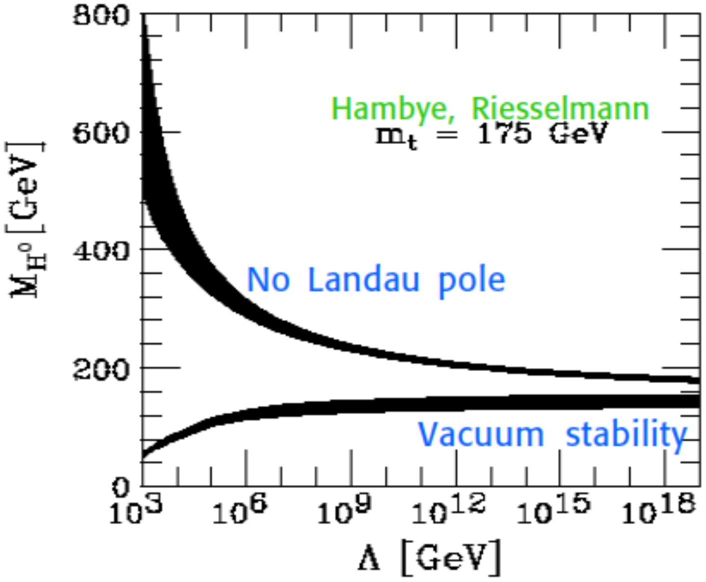

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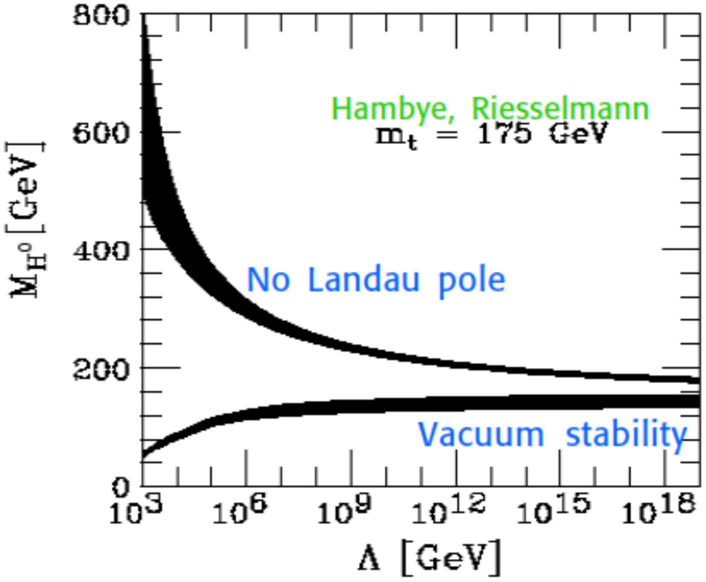
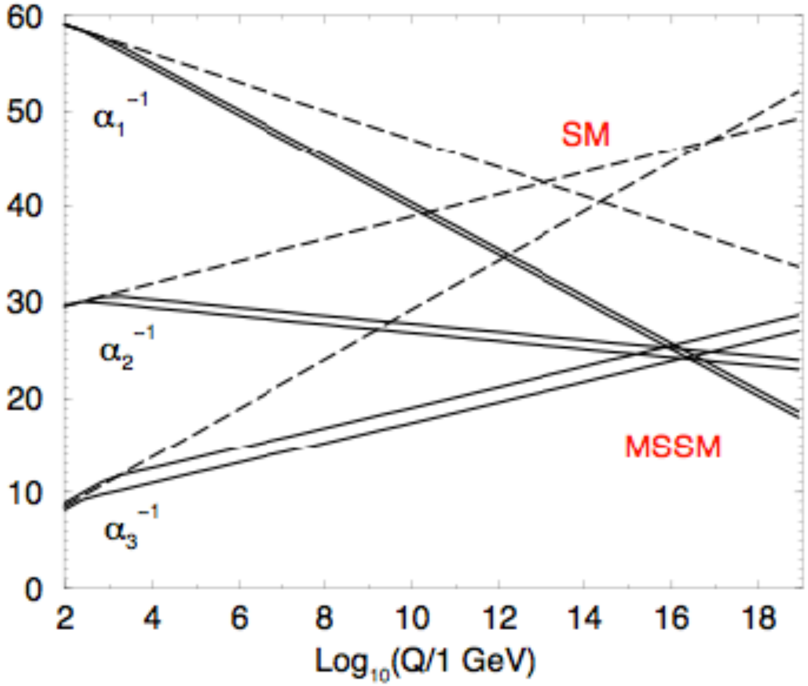
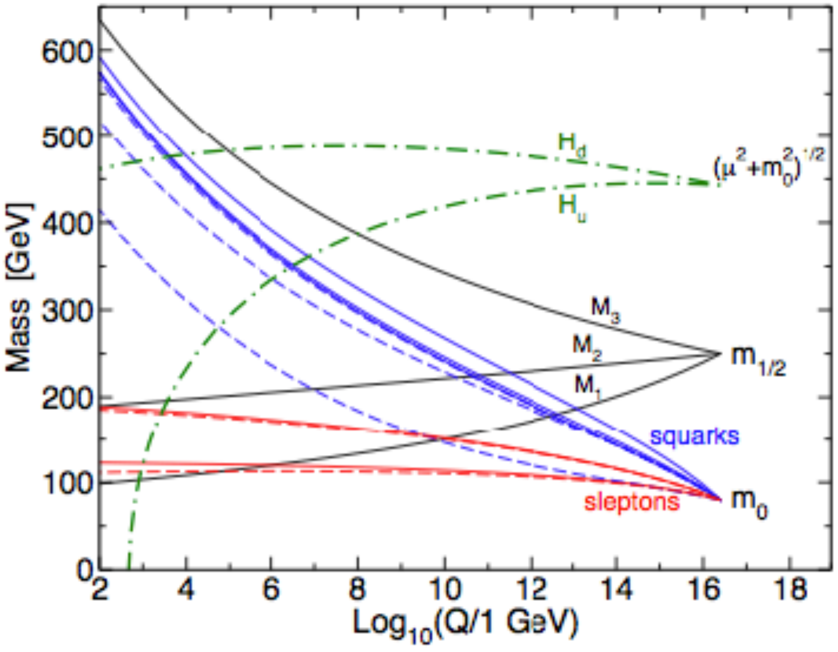


Supersymmetry – arguably the best proposition for beyond the SM physics

Arguments in favor for supersymmetry

- solves the SM hierarchy problem: bosons enjoy the same protection as fermions
- explains gauge coupling unification
- and EWSB via radiative corrections





- provides candidates for dark matter (e.g. neutralino)

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

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

gluinos, neutralinos are Majorana fermions
to be checked experimentally!

- Exact supersymmetry: no new parameters!

  but inconsistent with experiment

- Must be broken: this is where many arbitrary parameters enter

- Once parameters fixed: completely computable, mathematically consistent theory up to M_{GUT}

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should we give up supersymmetry????

Even before the LHC the minimal SUSY was under severe pressure:

- dim-4 B- and L-violating operators → extra symmetry (e.g. R-parity)
- possible flavor and CPV → strong constraints on the parameter space
- already LEP2 limit on Higgs mass >114 GeV required fine tuning

with 125 GeV even more

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Supersymmetry with R-symmetry

Continuous R-symmetry can ameliorate the above problems by

- removing dim-4 B- and L-violating terms, and dim-5 in proton decay
- removing soft tri-linear scalar couplings
- suppressing large contributions to flavor-violating observables
- suppressing the production cross sections for squarks, relax search limits

Outline

- R-symmetry
- Structure of the minimal SUSY with R-symmetry (MRSSM)
- Confronting the experiment
    - Higgs mass
    - electroweak precison observables
    - constraints from LHC

based on:

Choi, Drees, JK, Kim, Popenda, Zerwas, Phys.Lett.B 672 (2009) 246
Choi, Choudhury, Freitas, JK, Zerwas, Phys.Lett. B697 (2011) 215
Kotlarski, JK, Kalinowski, Acta Phys. Polon. B44 (2013)
Diessner, JK, Kotlarski, Stockinger, JHEP12 (2014) 124
Diesner, JK, Kotlarski, Stockinger, arXiv:1504.05386

- Summary

Supersymmetry

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

superfields

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

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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 $\hat{G}^\alpha \ni \lambda^\alpha + \theta^\alpha D$ 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 $\theta \to e^{i\alpha}\theta$

[Fayet ‘76; Salam & Strathdee, ...]

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

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

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

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

➡ are automatically R-symmetric

R-symmetry

- Nelson-Seiberg theorem: R-sym connected to SUSY breaking
- R-symmetry cannot be broken spontaneously
- two options: exact or broken explicitly

in the MSSM it is broken by soft gaugino masses $M_{\tilde{G}} \tilde{G}^{\alpha} \tilde{G}_{\alpha}$

- for exact we need

R(superpotential)=2 $\int d^2\theta \, W$

R(soft terms) =0

- freedom to assign the R-charges to chiral superfields

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our choice: SM particles have R=0, superpartners R≠0

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

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

Constraints from R-symmetry

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

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  - 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 $M_{\tilde{G}} \tilde{G}^{\alpha} \tilde{G}_{\alpha}$

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

Minimal R-symmetric SSM

[Kribs Poppitz Weiner 2007]

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

- chiral superfields in the adjoint representation

e.g. SU(3) octet

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

$$R(\hat{O}) = 0 \Rightarrow R(O) = 0,\ R(\tilde{O}) = -1$$

to build a Dirac gluino $\tilde{g}_D = \tilde{O}_L + \tilde{g}_R$

- similarly for the SU(2) triplet $\hat{T}$
  and U(1) singlet $\hat{S}$ superfields

- new scalar fields in adjoint representations:
  octet of sgluons O,
  triplet of T
  and a singlet S

- super-soft Dirac mass generates sgluon
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- two chiral iso-dublets with R-charge 2

$$\hat{R}_u,\; \hat{R}_d$$

to build a mu-type term

$$W \ni \mu_d \hat{R}_d \cdot \hat{H}_d + \mu_u \hat{R}_u \cdot \hat{H}_u$$

- other couplings allowed

$$W \ni \Lambda_d \hat{R}_d \cdot \hat{T}\hat{H}_d + \lambda_d \hat{S}\hat{R}_d \cdot \hat{H}_d + (u \to d)$$

important to get Higgs boson mass

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➡ important consequences for collider physics, dark matter, flavour physics,...

soft scalar masses

R-symmetric soft masses can be generates as

- super-soft Dirac mass $\int d^2\theta \, \frac{\hat{W}'^\alpha}{M} \, \mathrm{Tr}\, \hat{G}^\alpha \hat{\Sigma} \to \; M^D \tilde{G}\tilde{G}'$

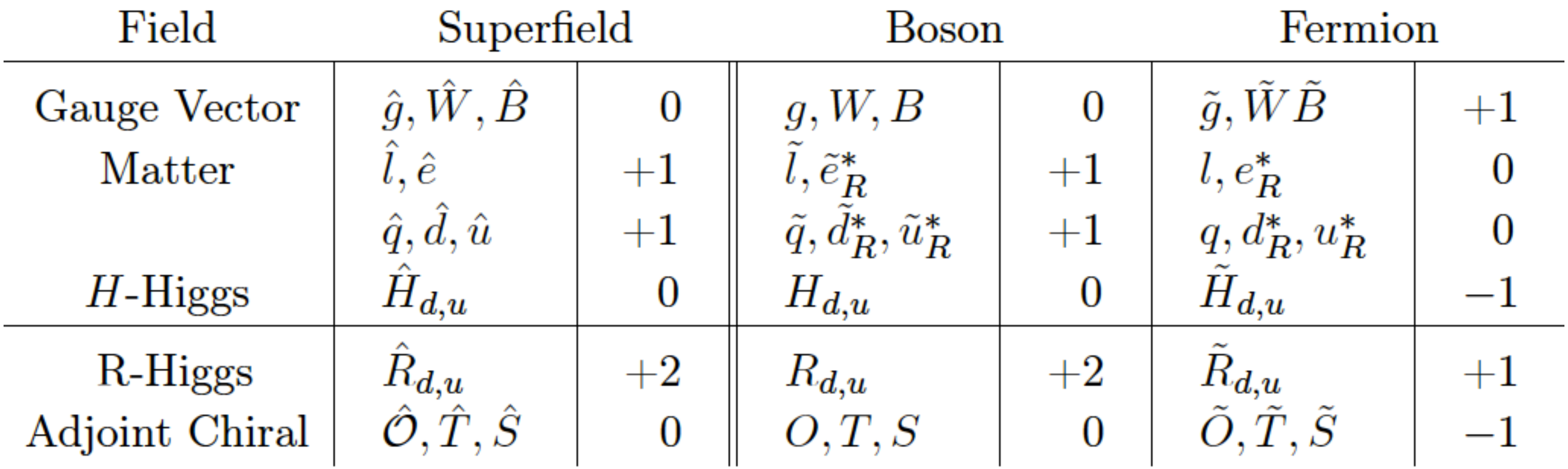
  with D-type spurion $\langle \hat{W}'^\alpha \rangle = \theta^\alpha D'$

- B_{mu}-term $\int d^4\theta \, \frac{\hat{X}^\dagger \hat{X}}{M^2} \, \hat{H}_u \hat{H}_d \; \to \; B_\mu H_u H_d$
- masses for R-Higgses $\int d^4\theta \, \frac{\hat{X}^\dagger \hat{X}}{M^2} \, \hat{R}_d^\dagger \hat{R}_d \; \to \; M_{R_d}^2 (|R_d^+|^2 + |R_d^0|^2)$
- masses for scalar fields $\int d^4\theta \, \frac{\hat{X}^\dagger \hat{X}}{M^2} \, \mathrm{Tr}\, \hat{\Sigma}^\dagger \hat{\Sigma} \; \to \; M_\sigma^2 (\sigma^2 + \sigma^{*2})$

with F-type spurion $\langle \hat{X} \rangle = \theta^2 F_X$

MRSSM

R-charges of the superfields and their component fields



Field	Superfield		Boson		Fermion	
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Matter	$\hat{l}, \hat{e}$	$+1$	$\tilde{l}, \tilde{e}^*_R$	$+1$	l, e^*_R	0
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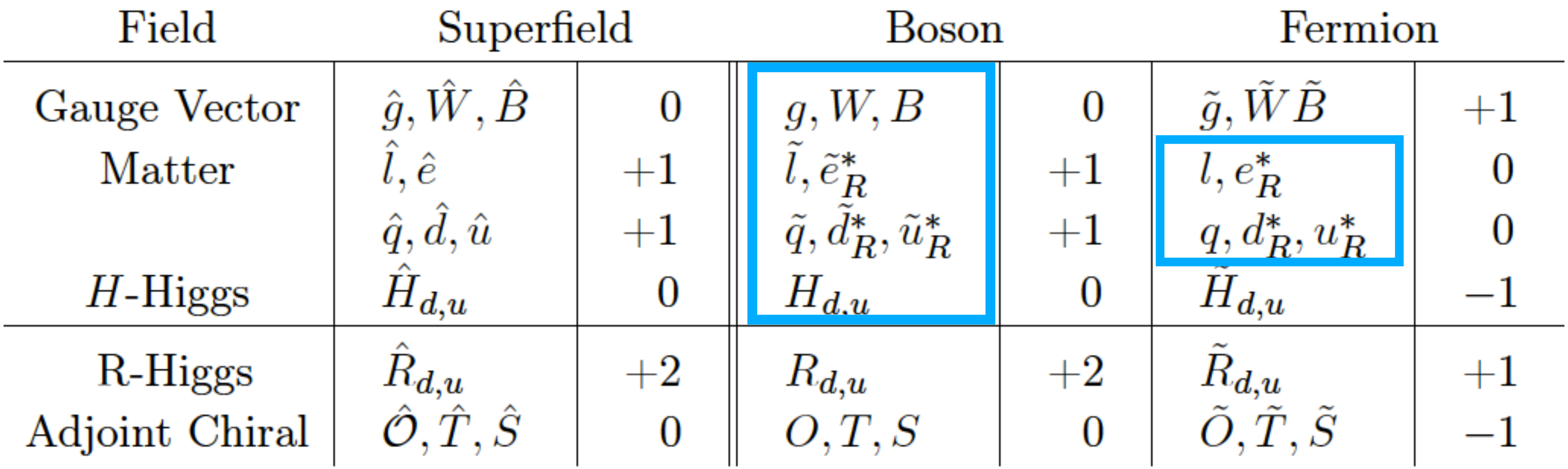

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matter, gauge and Higgs as in MSSM

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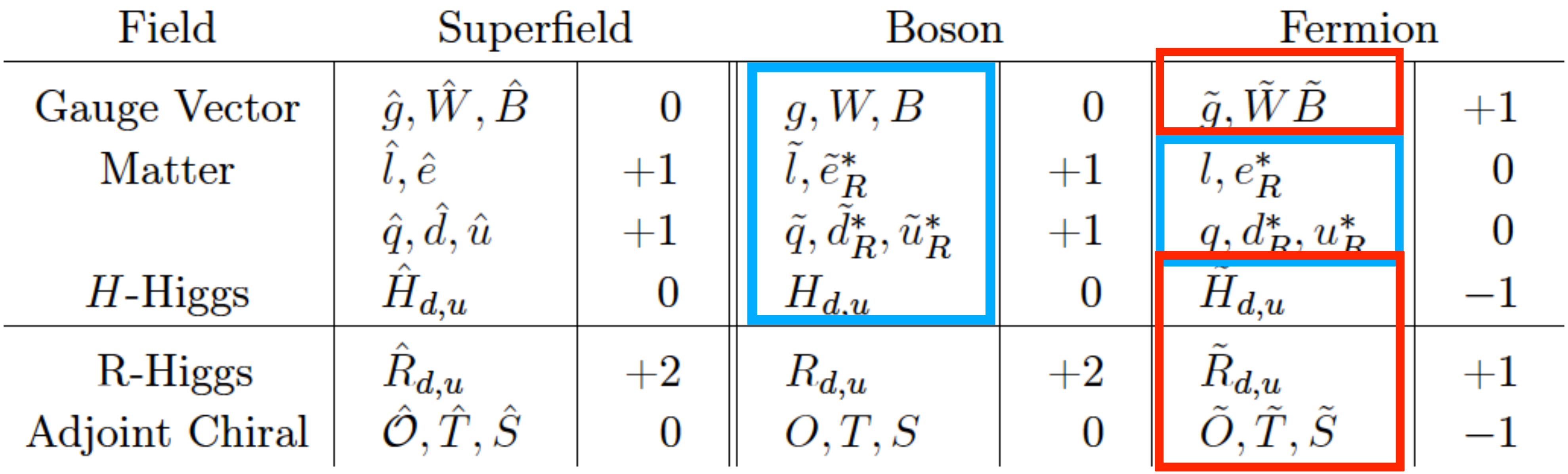

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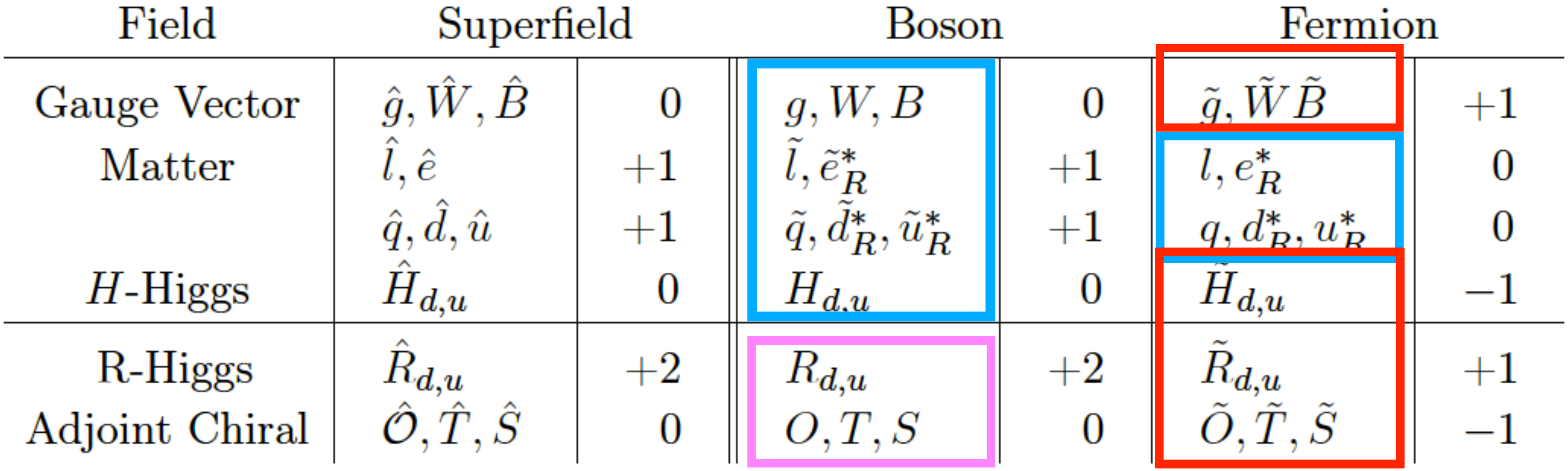

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gluinos and neutralinos are Dirac
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gauge-adjoint scalars (e.g. sgluons)
and R-Higgs bosons

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

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

MRSSM confronting experiment

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

Diessner, JK, Kotlarski, Stockinger, JHEP12 (2014) 124

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Answer not obvious because:

- mixing with other states lowers the tree level mass
- 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
- the W mass (and other PO) affected by loops (lecture by A. Pich)
- LHC and flavor constraints

lightest Higgs – tree level

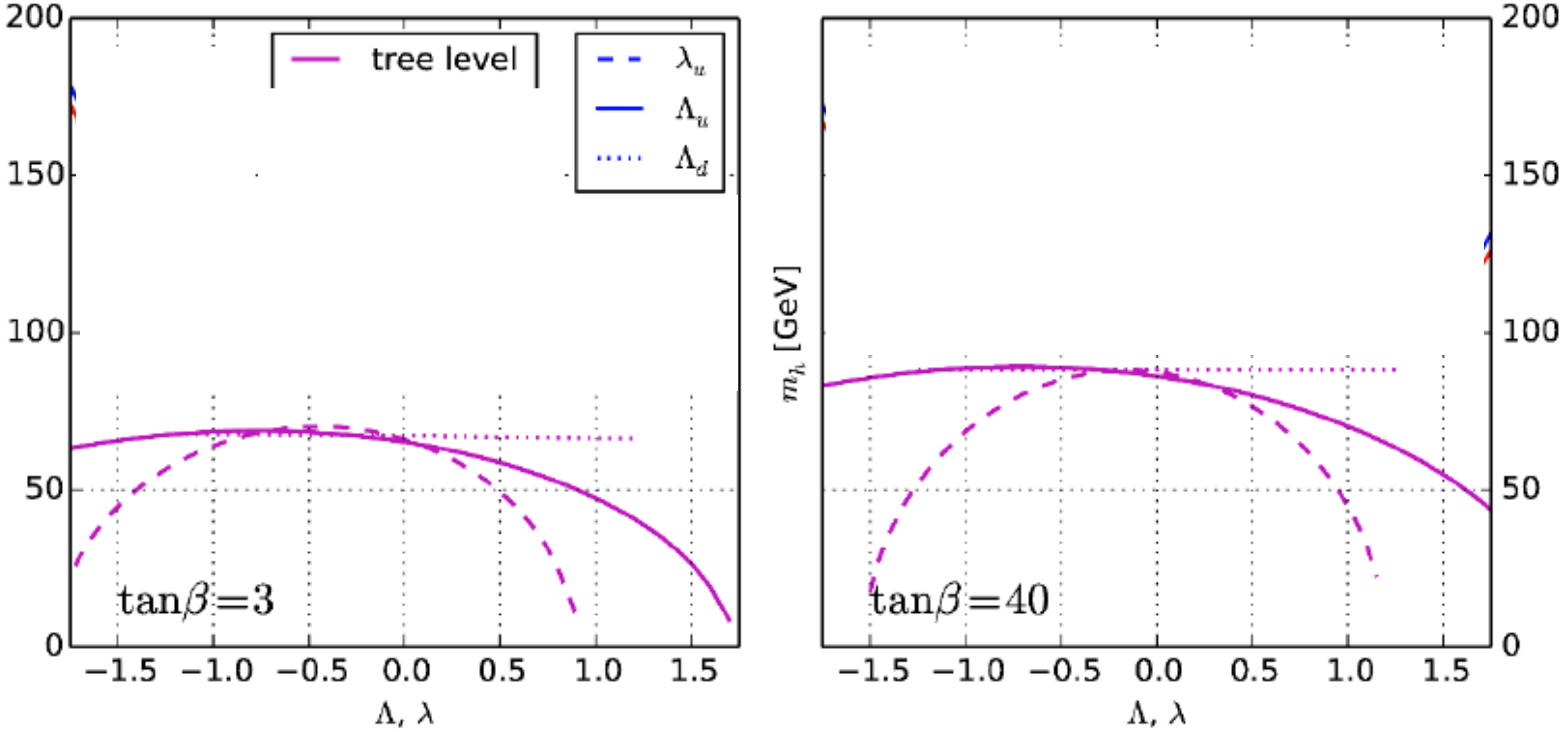
- EW symmetry breaking triggered by vev's of neutral fields

$$H_d^0 = \frac{1}{\sqrt{2}}(v_d + \phi_d + i\sigma_d), \quad H_u^0 = \frac{1}{\sqrt{2}}(v_u + \phi_u + i\sigma_u) \ ,$$
$$T^0 = \frac{1}{\sqrt{2}}(v_T + \phi_T + i\sigma_T), \quad S = \frac{1}{\sqrt{2}}(v_S + \phi_S + i\sigma_S) \ ;$$

- 4 scalar neutral fields $\{\phi_d, \, \phi_u, \, \phi_T, \, \phi_S\}$ mix to give physical Higgses

$$\mathcal{M}_{H^0} = \begin{pmatrix} \mathcal{M}_{\rm MSSM} & \mathcal{M}_{21}^T \\ \mathcal{M}_{21} & \mathcal{M}_{22} \end{pmatrix}$$

lightest Higgs – tree level



- approximate formula for the lightest Higgs at tree level

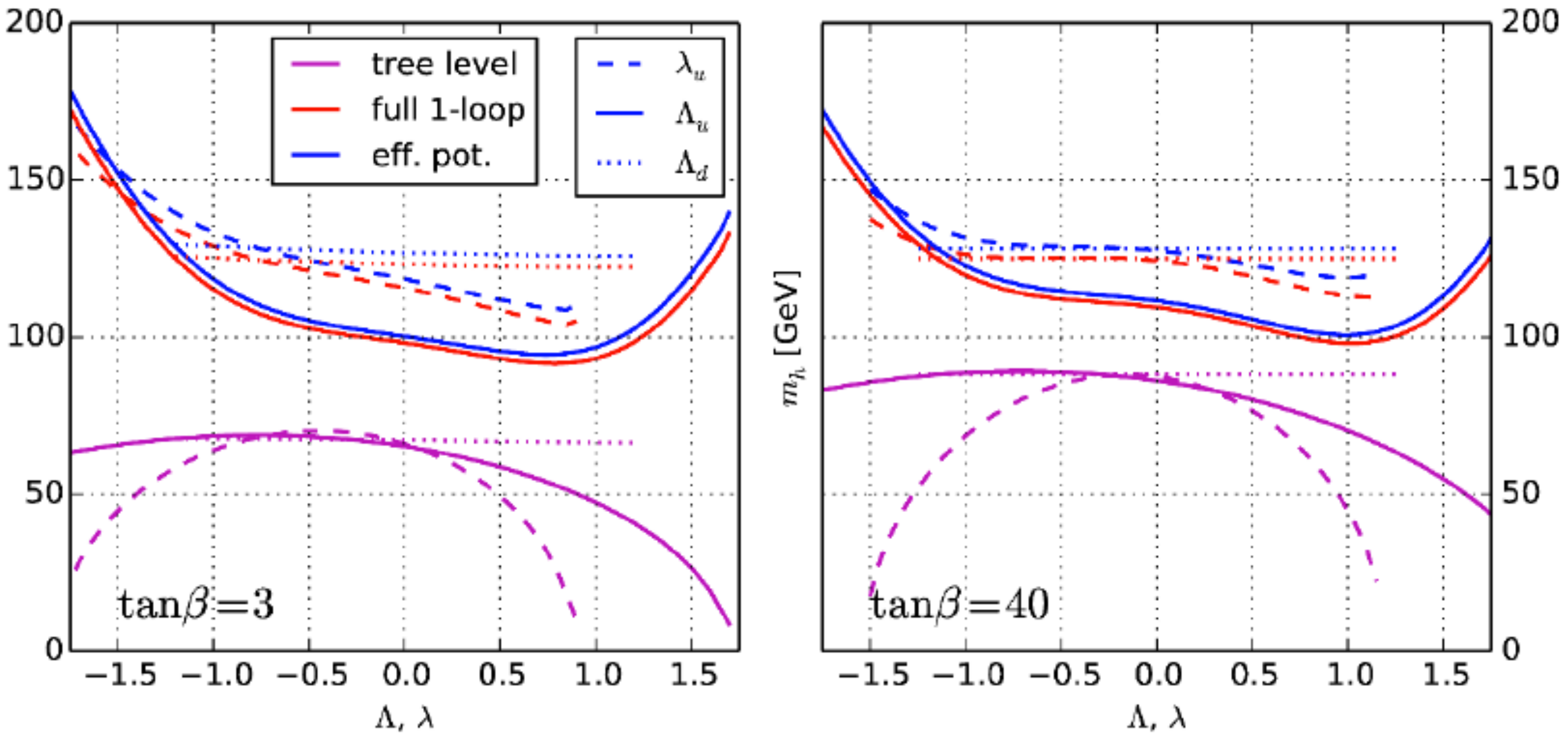
$$m^2_{H_1,\text{approx}} = m_Z^2\cos^2 2\beta - v^2\left(\frac{\left(g_1 M_B^D + \sqrt{2}\lambda\mu\right)^2}{4(M_B^D)^2+m_S^2} + \frac{\left(g_2 M_W^D + \Lambda\mu\right)^2}{4(M_W^D)^2+m_T^2}\right)\cos^2 2\beta$$

under simplifying assumptions of large pseudoscalar A mass and

$\lambda = \lambda_u = -\lambda_d,\ \Lambda = \Lambda_u = \Lambda_d,\ \mu_u = \mu_d = \mu$ and $v_S \approx v_T \approx 0$:

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

lightest Higgs – full one-loop level



- large enhancement of the tree-level value
  - ~1 TeV stops without LR mixing not enough
  - important contributions from $\Lambda, \lambda \sim -1$
  - stops ~ 0.5 TeV would also work fine

calculations done in DRbar, using SARAH, FeynArts, FormCalc and SPheno

W mass – full one-loop level

Beyond tree-level

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

using $\hat{s}_W^2 = 1 - \frac{m_W^2}{m_Z^2\hat{\rho}}$

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

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

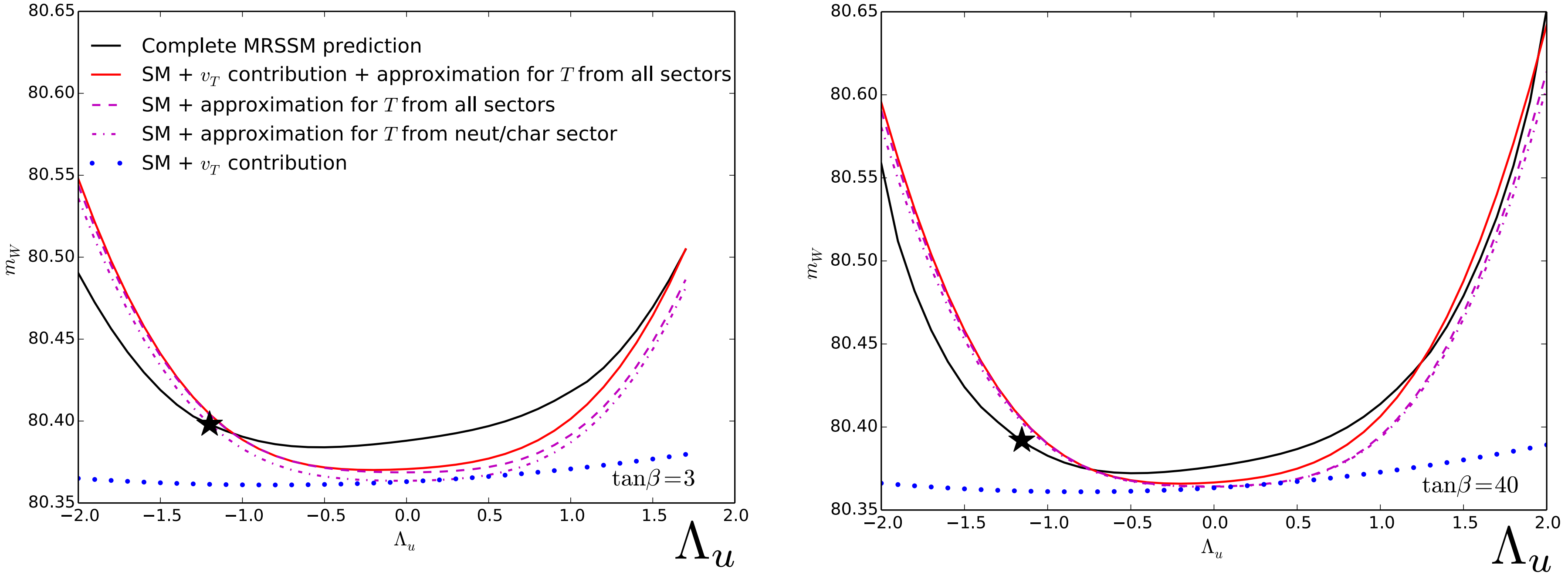
need to calculate $\hat{\alpha}$, $\hat{\rho}$, and $\Delta\hat{r}_W$

instructive to expand

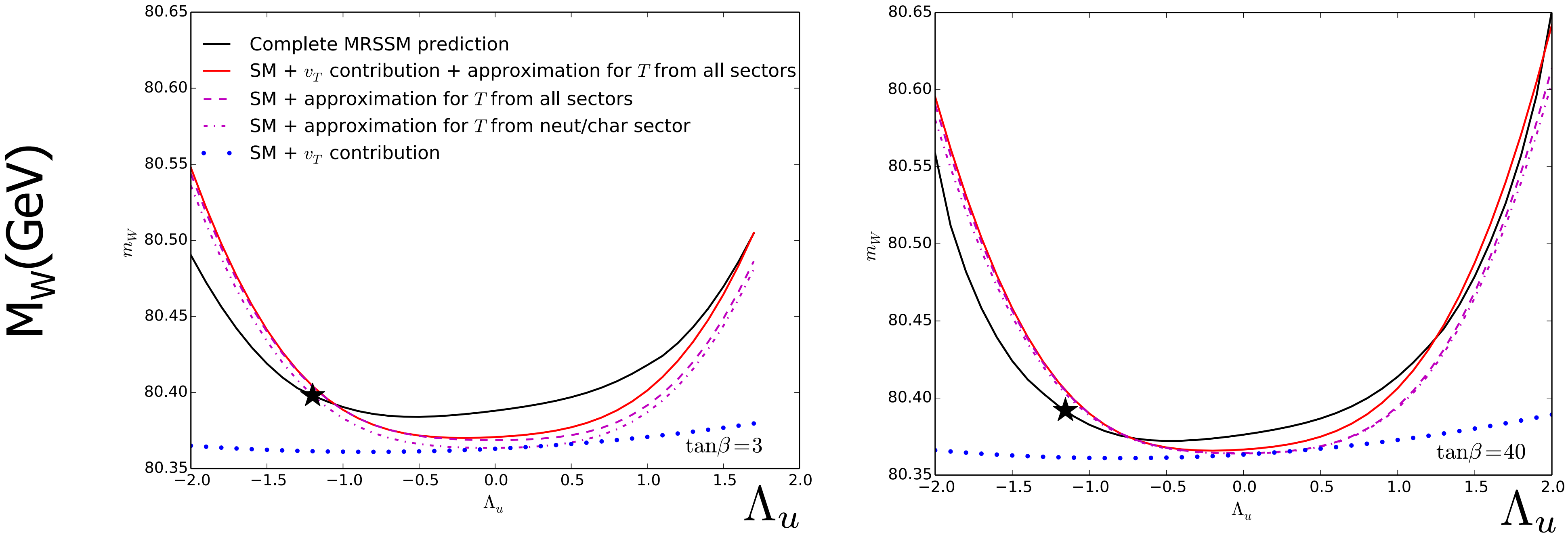
$$m_W \approx m_W^{\mathrm{ref}} + \frac{m_Z\hat{c}_W}{2(\hat{c}_W^2-\hat{s}_W^2)}\left[\hat{c}_W^2\delta(\hat{\rho}) - \hat{s}_W^2(\delta(\Delta\hat{r}_W)+\delta(\hat{\alpha}))\right]$$

W mass – full one-loop level

M_W(GeV)



W mass – full one-loop level



to understand qualitatively expand in terms of S,T,U parameters

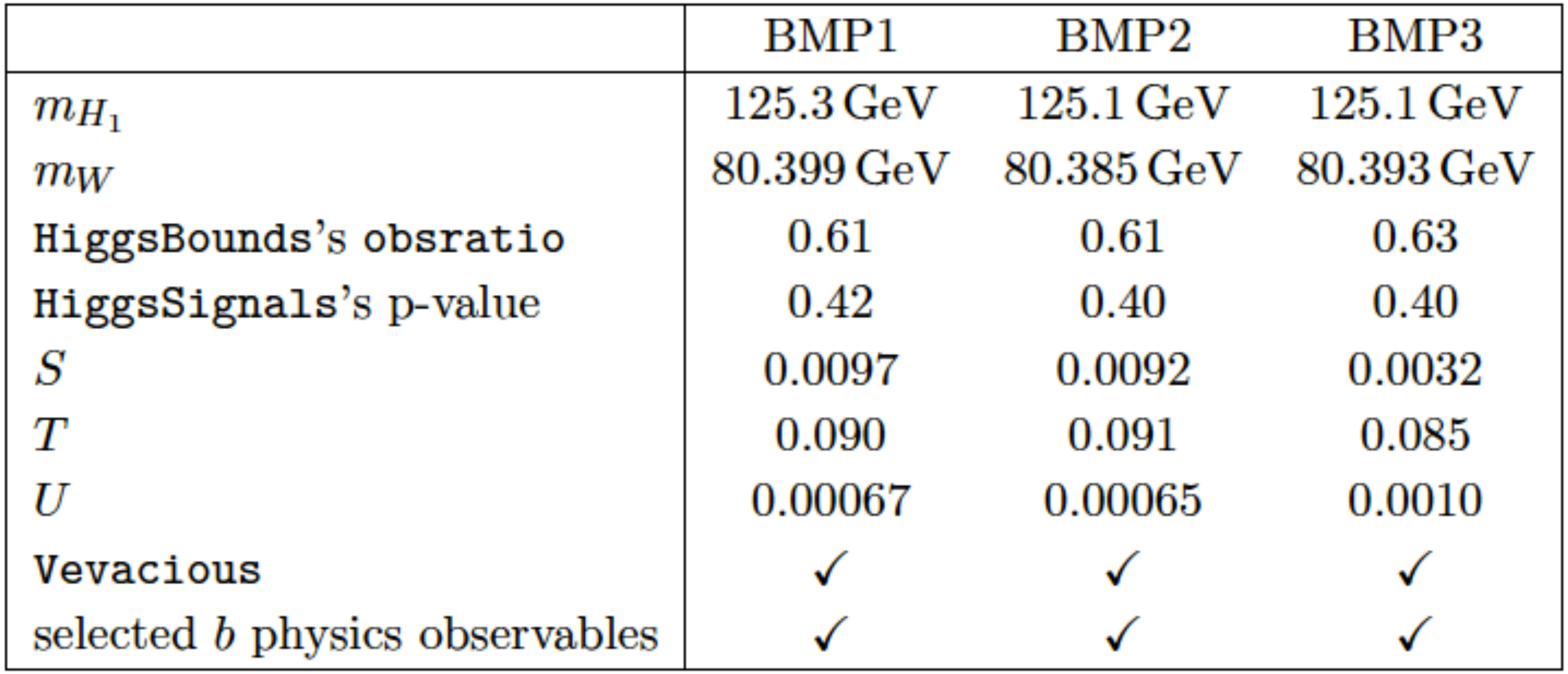
$$m_W = m_W^{\text{ref}} + \frac{\hat{\alpha} m_Z \hat{c}_W}{2(\hat{c}_W^2 - \hat{s}_W^2)} \left(-\frac{S}{2} + \hat{c}_W^2 T + \frac{\hat{c}_W^2 - \hat{s}_W^2}{4\hat{s}_W^2} U \right)$$

dominant contribution to the W mass from T~0.09

which receives large corrections from chargino/neutralino sector $\sim \Lambda_u^4$

Benchmarks

three benchmarks with $\tan\beta = 3, 10, 40$



	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	✓	✓	✓

Higgs at two loops

Antonio Pich ➔ before calculating full one-loop, check dominant two-loop from top/stop because of large top Yukawa

Higgs at two loops

Antonio Pich ➔ before calculating full one-loop, check dominant two-loop from top/stop because of large top Yukawa

In the MSSM the answer is well known

The MRSSM is distinctively different

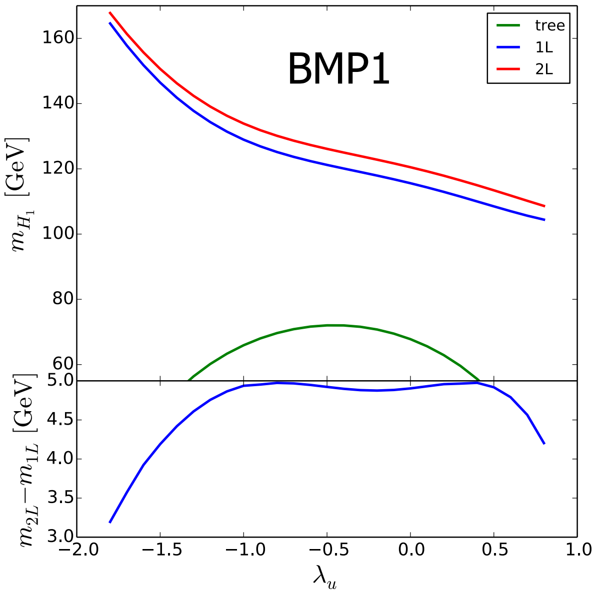
- new large couplings $\Lambda, \lambda \sim -1$, is perturbativity still at work?
- new sectors enter the game: Dirac gluinos and scalar gluons

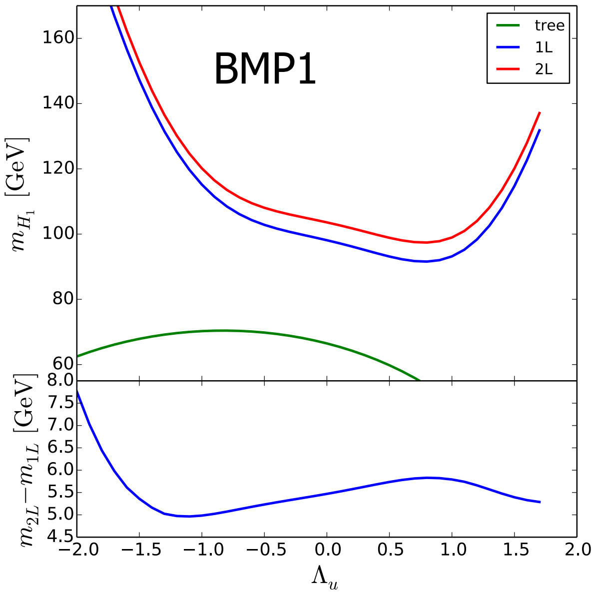
Recent release of SARAH provides tools to calculate in eff. potential

Goodsell, Nickel, Staub, arXiv:1411.0675

Higgs at two loops

Diesner, JK, Kotlarski, Stockinger, arXiv:1504.05386





2-loop EW corrections small, inspite large 1-loop

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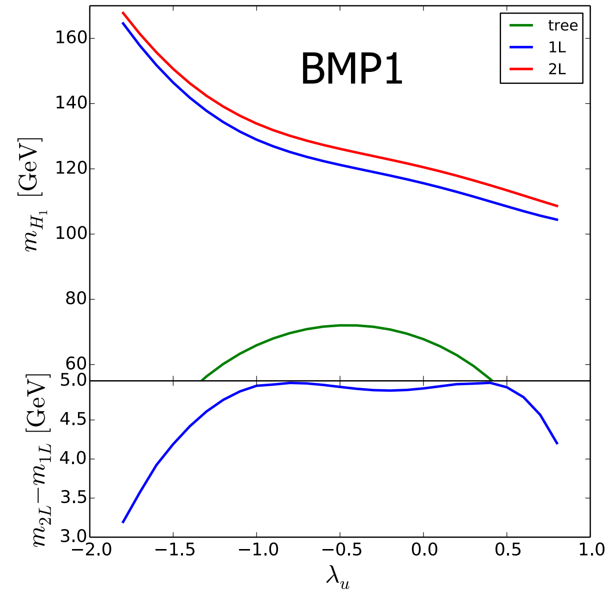
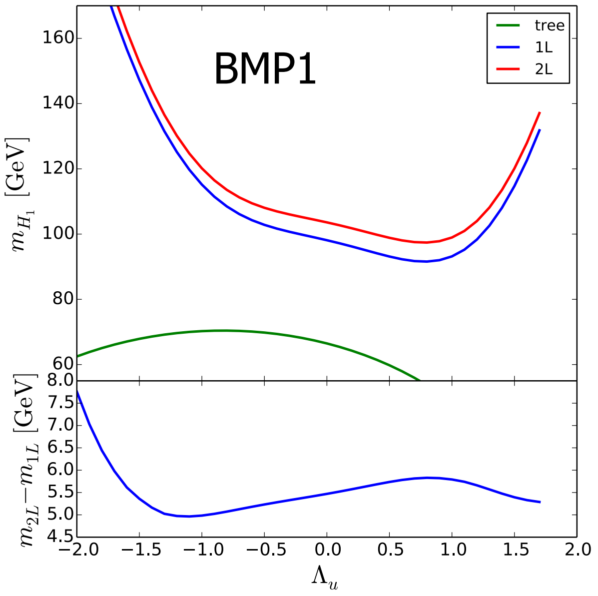
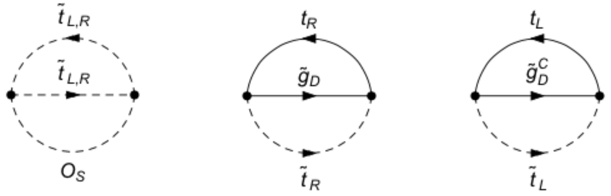
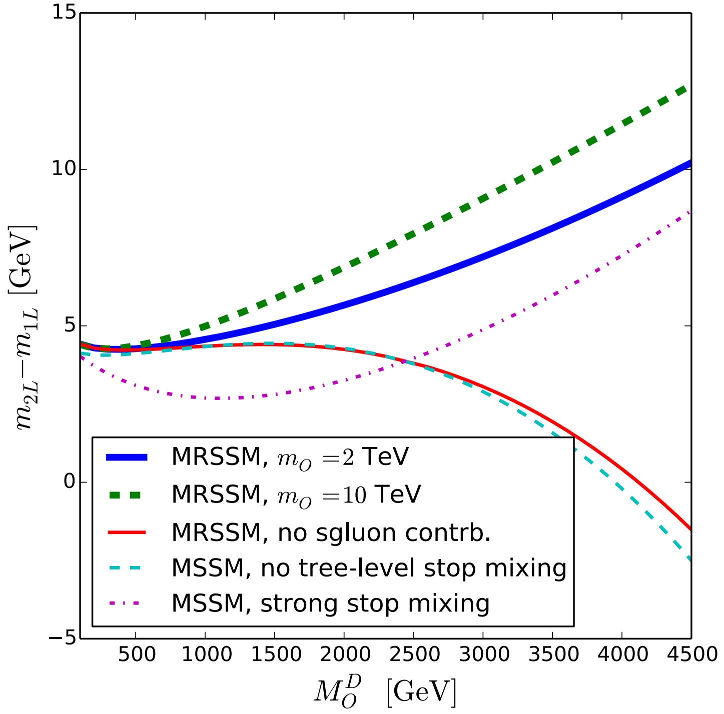




2-loop EW corrections small, inspite large 1-loop

QCD corrections

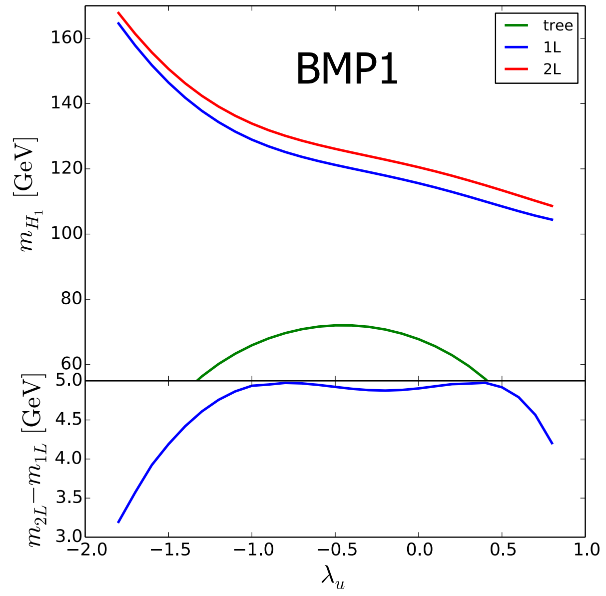


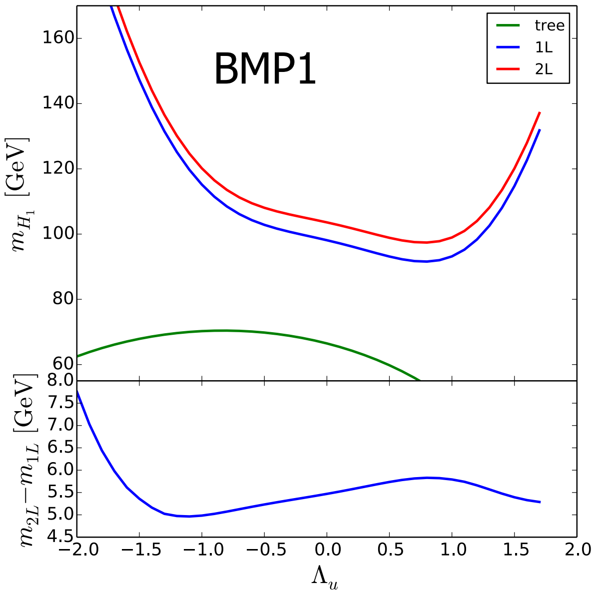


without sgluon, MRSSM ~ MSSM when no LR mixing
with sgluon, MRSSM ~ MSSM with LR mixing
but for different reason

Higgs at two loops

Diesner, JK, Kotlarski, Stockinger, arXiv:1504.05386





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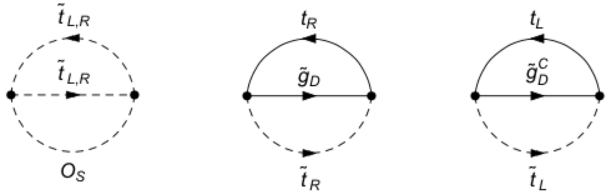

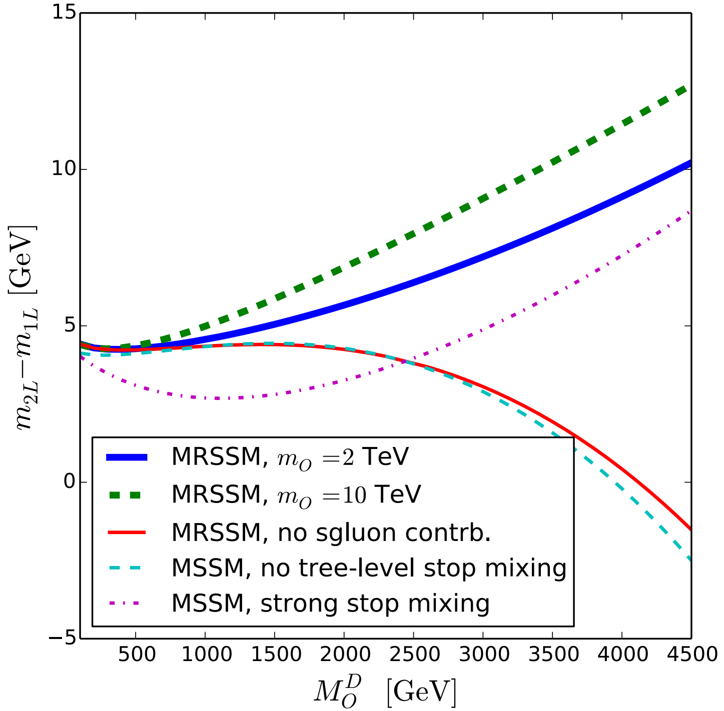

without sgluon, MRSSM ~ MSSM when no LR mixing
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but for different reason

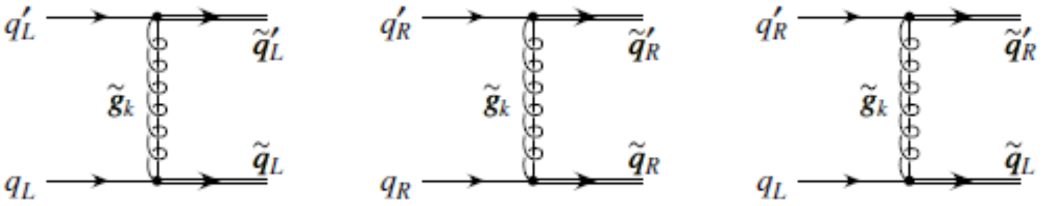
QCD corrections +few GeV ➡ Λ_u can be smaller

Colored sector

Choi Drees Freitas Zerwas ’08

Dirac gluinos

e.g. squark pair ptoduction



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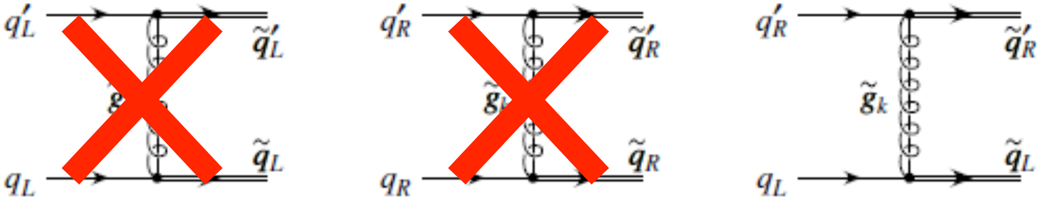
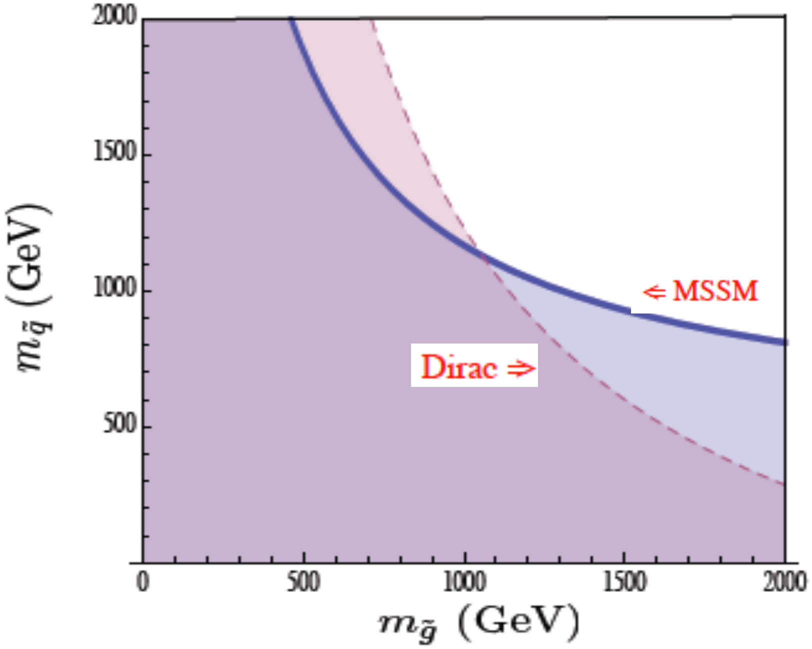


✧ lower sensitivity to squarks
✧ higher sensitivity to gluinos



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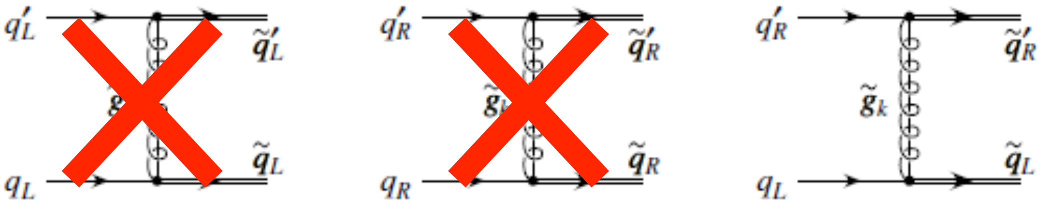

- lower sensitivity to squarks
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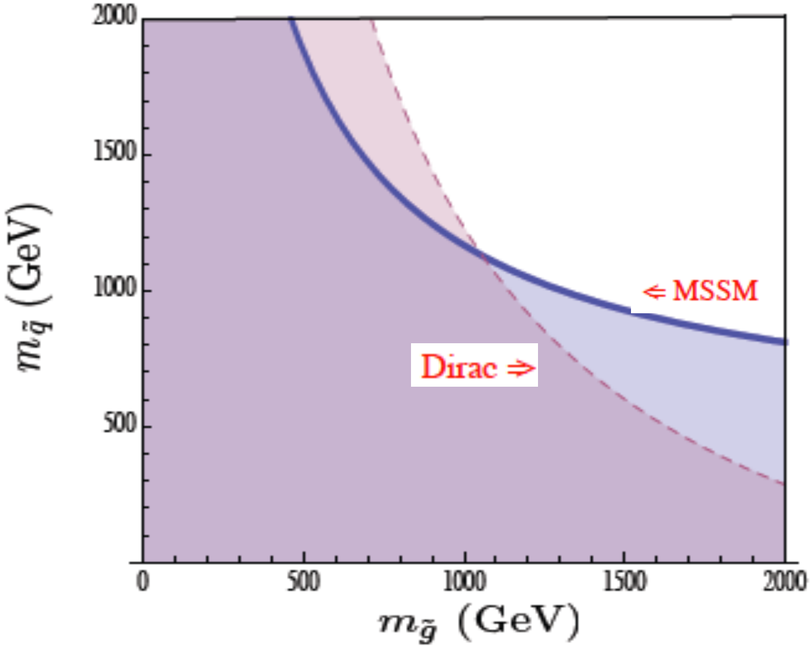
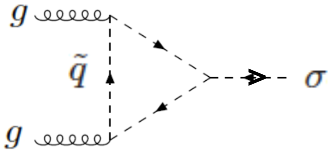


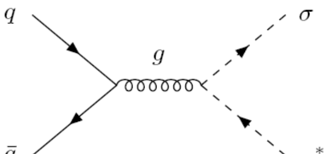
Sgluons have tree-level couplings

- to gluons and gluinos
- to squarks through the D-term

can be produced

- singly only via loop-induced coupling in ggF
- or in pairs





Summary

- Well motivated R-symmetric SUSY model discussed
- Gauginos become Dirac particles, new scalar partners
- Viable benchmarks with
  - ~ 125 GeV lightest Higgs boson mass
  - agreement with EWPO and flavor physics
  - stable vacuum
  - consistent with LHC constraints
- Conserved R-charge restricts production channels and decay modes

distinct phenomenology at colliders

sgluons can be light and seen at the LHC

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- Well motivated R-symmetric SUSY model discussed
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distinct phenomenology at colliders

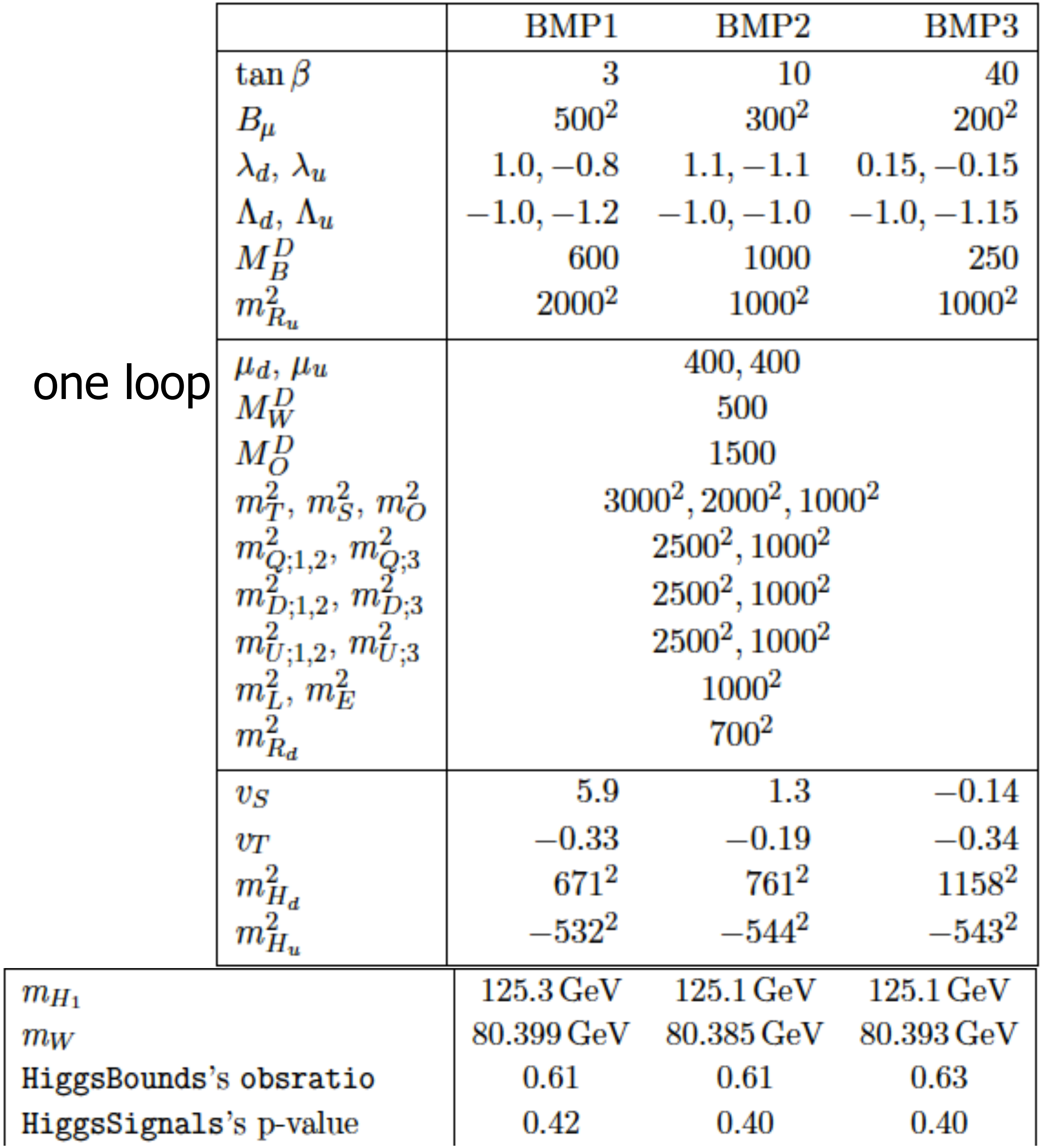
sgluons can be light and seen at the LHC

Many things to do: work out the full LHC phenomenology, dark matter etc.

work in progress

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:

including two-loop corr.

Λ_u reduces to

one loop

	BMP1	BMP2	BMP3			
$\tan\beta$	3	10	40			
B_μ	500^2	300^2	200^2			
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$\Lambda_d,\, \Lambda_u$	$-1.0, -1.2$	$-1.0, -1.0$	$-1.0, -1.15$	-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					
$m_T^2,\, m_S^2,\, m_O^2$	$3000^2, 2000^2, 1000^2$					
$m_{Q;1,2}^2,\, m_{Q;3}^2$	$2500^2, 1000^2$					
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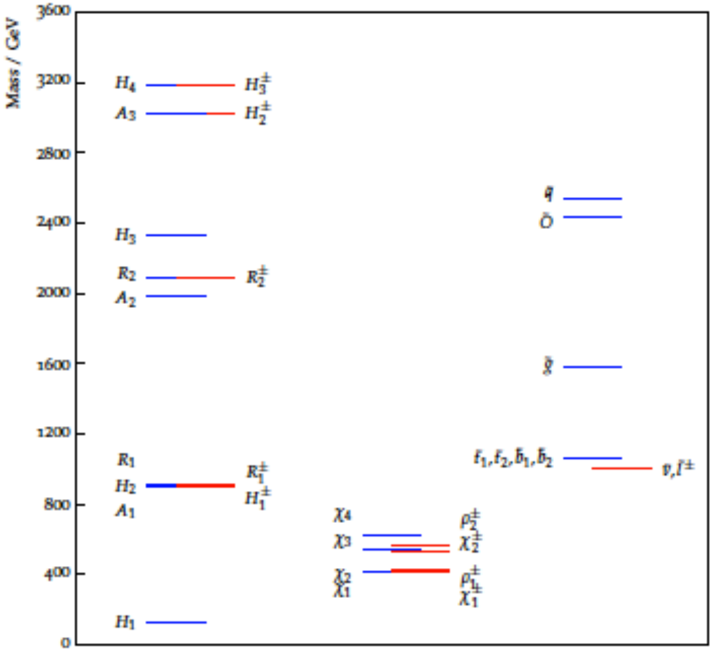
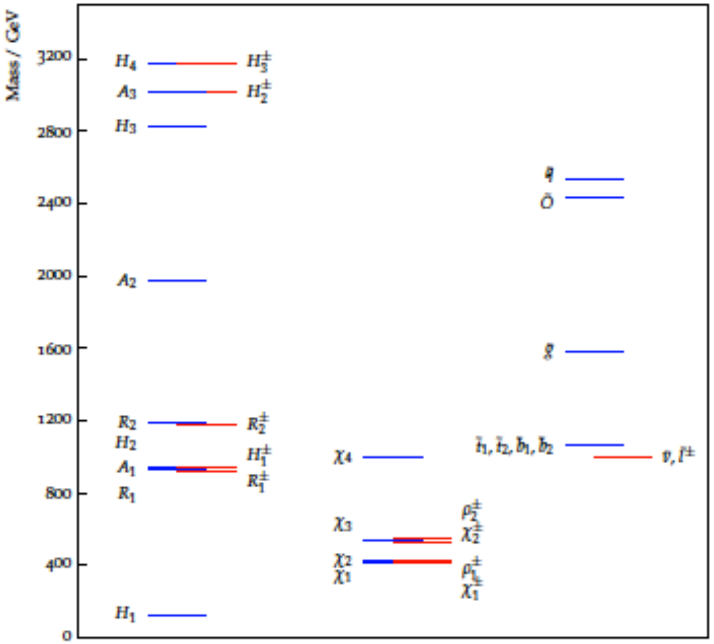
v_S	5.9	1.3	-0.14	5.2	1.01	-0.22
v_T	-0.33	-0.19	-0.34	-0.25	-0.02	-0.21
$m_{H_d}^2$	671^2	761^2	1158^2	674^2	764^2	1160^2
$m_{H_u}^2$	-532^2	-544^2	-543^2	-502^2	-512^2	-516^2
m_{H_1}	125.3 GeV	125.1 GeV	125.1 GeV	125.3 GeV	125.5 GeV	125.4 GeV
m_W	80.399 GeV	80.385 GeV	80.393 GeV	80.397 GeV	80.381 GeV	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

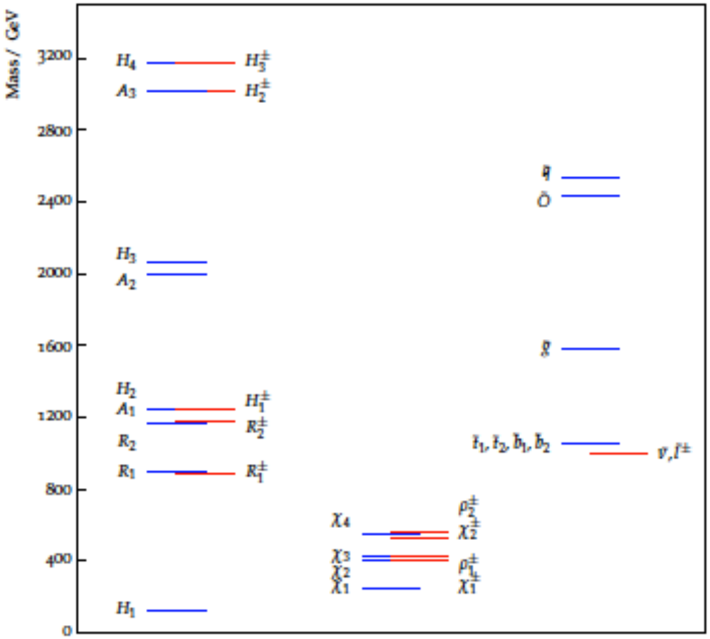
BMP1



BMP2



BMP3



Colored scalars: sgluons

Tree-level couplings

- $\sigma\sigma^* g$ and $\sigma\sigma^* gg$ couplings as required by gauge invariance
- to gluinos $-\sqrt{2}\, i\, g_s\, f^{abc}\, \overline{\tilde{g}'^a_L}\, \tilde{g}^b_R\, \sigma^c_C + \mathrm{h.c.}$
- Dirac gluino mass => trilinear scalar couplings to squarks

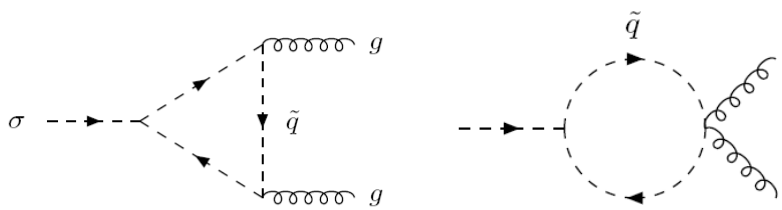
$$-\sqrt{2}\, g_s\, M^D_C\, (\sigma^a_C + \sigma^{a*}_C) \left(\tilde{q}^*_L \frac{\lambda^a}{2} \tilde{q}_L - \tilde{q}^*_R \frac{\lambda^a}{2} \tilde{q}_R \right)$$

vanish for degenerate L/R squarks

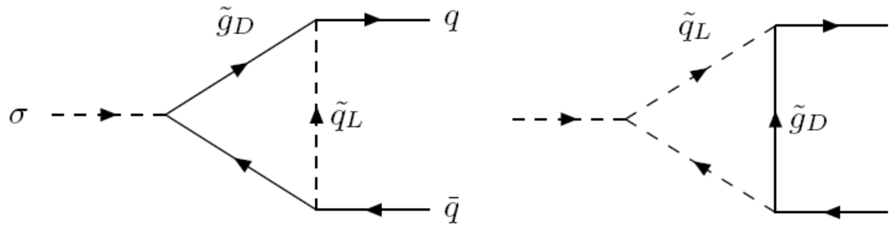
➡ Although R=0, single sgluon cannot be produced at treel level

Loop-induced couplings

- to a gluon or quark pair through diagrams with squarks or gluinos



(gluino loops vanish)

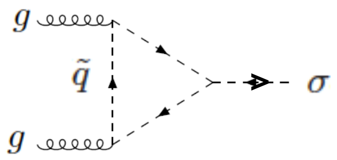


$\sim m_q$

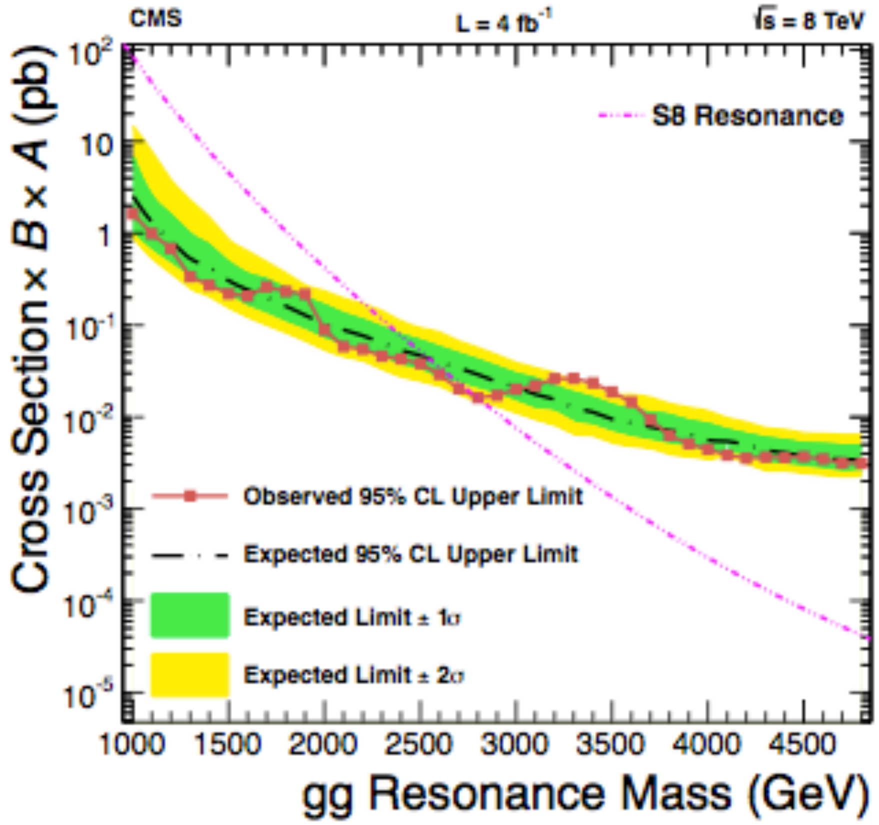
Choi, Drees, JK, Kim, Popenda, Zerwas ’09
Plehn Tait, ’09

Searching for sgluons

- At the LHC sgluons can be produced **singly** via



➡ exciting possibility of resonant s-channel sgluon production



exclusion up to ~ 2.5 TeV for a state s8
with full strength coupling

Han, Lewis, Liu, 1010.4309

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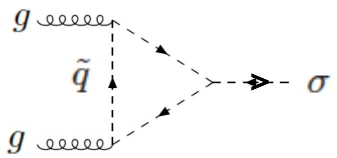

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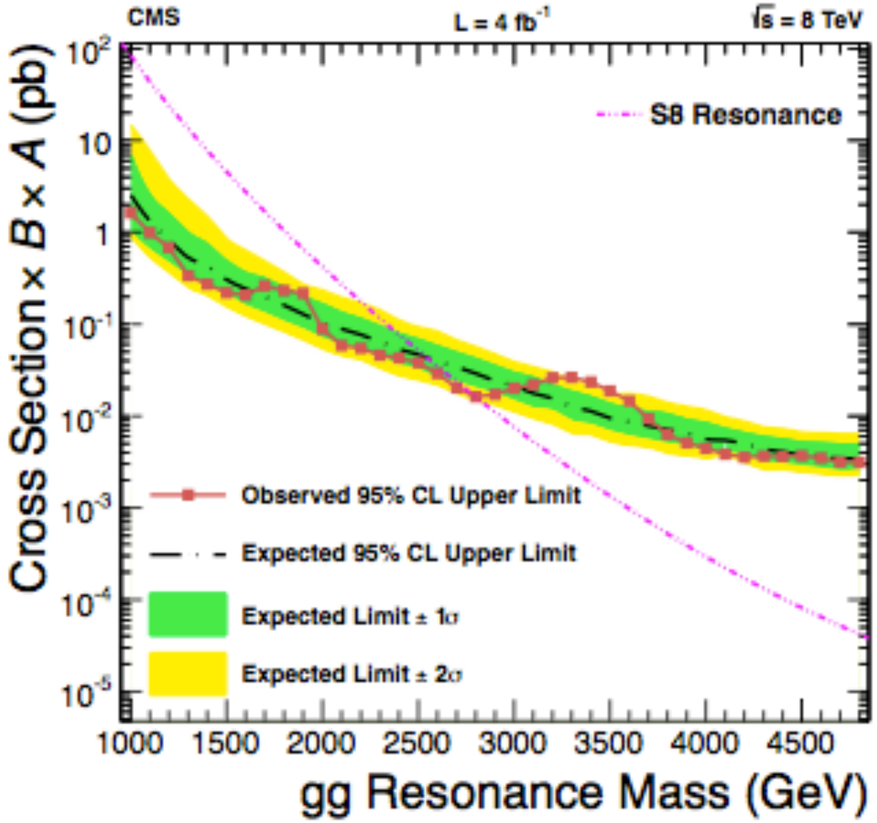
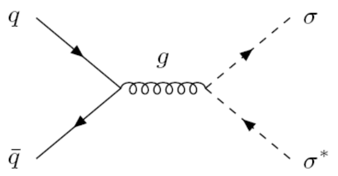


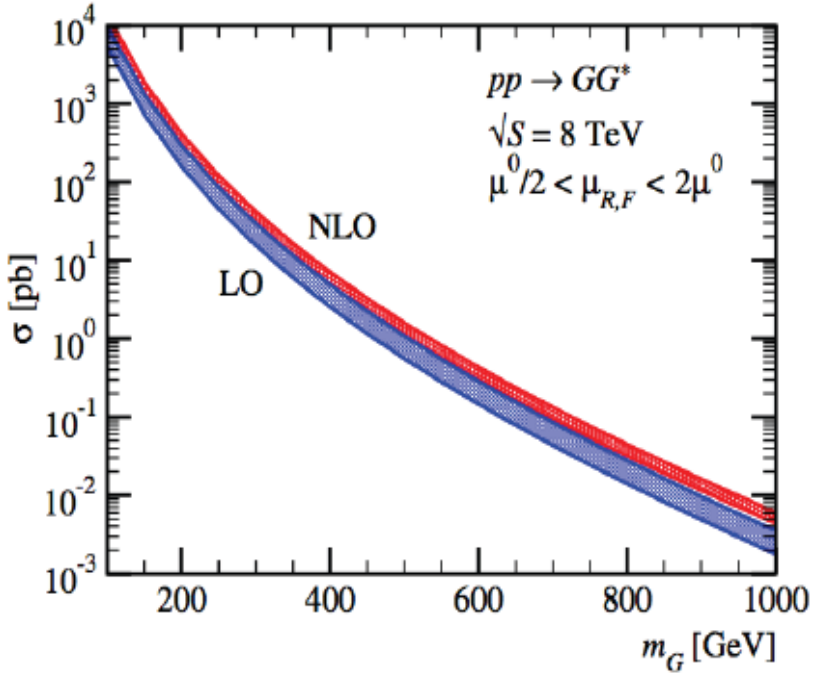
however, for loop-induced coupling factor ~ 10^{-5} suppression

exclusion up to ~ 2.5 TeV for a state s8 with full strength coupling

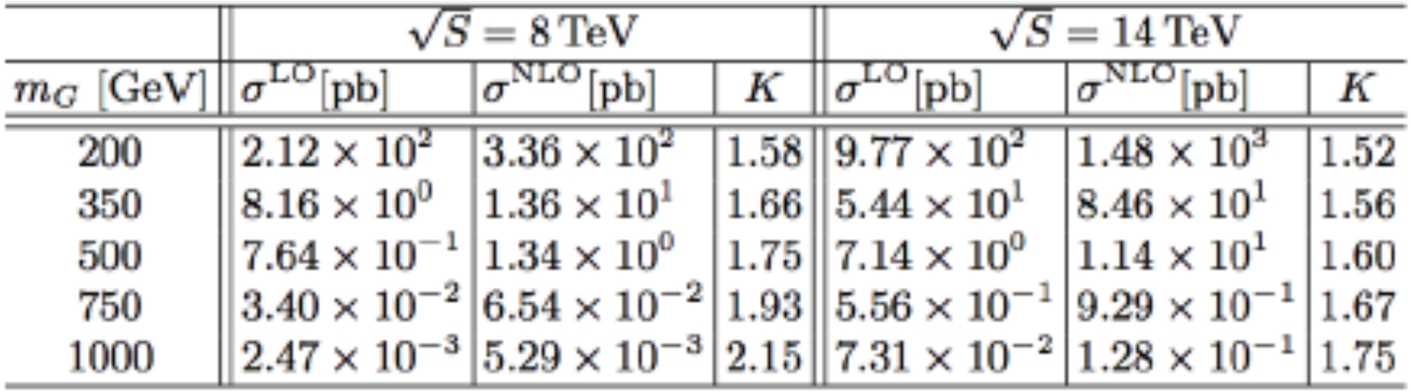
Han, Lewis, Liu, 1010.4309

- At the LHC sgluons can be also produced in pairs





MadGolem coll, arXiv:1203.6358.



	$\sqrt{S} = 8$ TeV			$\sqrt{S} = 14$ TeV		
m_G [GeV]	σ^{LO}[pb]	σ^{NLO}[pb]	K	σ^{LO}[pb]	σ^{NLO}[pb]	K
200	2.12×10^2	3.36×10^2	1.58	9.77×10^2	1.48×10^3	1.52
350	8.16×10^0	1.36×10^1	1.66	5.44×10^1	8.46×10^1	1.56
500	7.64×10^{-1}	1.34×10^0	1.75	7.14×10^0	1.14×10^1	1.60
750	3.40×10^{-2}	6.54×10^{-2}	1.93	5.56×10^{-1}	9.29×10^{-1}	1.67
1000	2.47×10^{-3}	5.29×10^{-3}	2.15	7.31×10^{-2}	1.28×10^{-1}	1.75

at 8 TeV in tttt channel, excluded up to ~ 850 GeV