Dirac Gauginos and the Di-Photon Excess

Julia Harz
(LPTHE / ILP Paris)

based on 1605.05313 [hep-ph]

in collaboration with K. Benakli, L. Darme, M. Goodsell

GDR Terascale, Nantes

24/05/2016

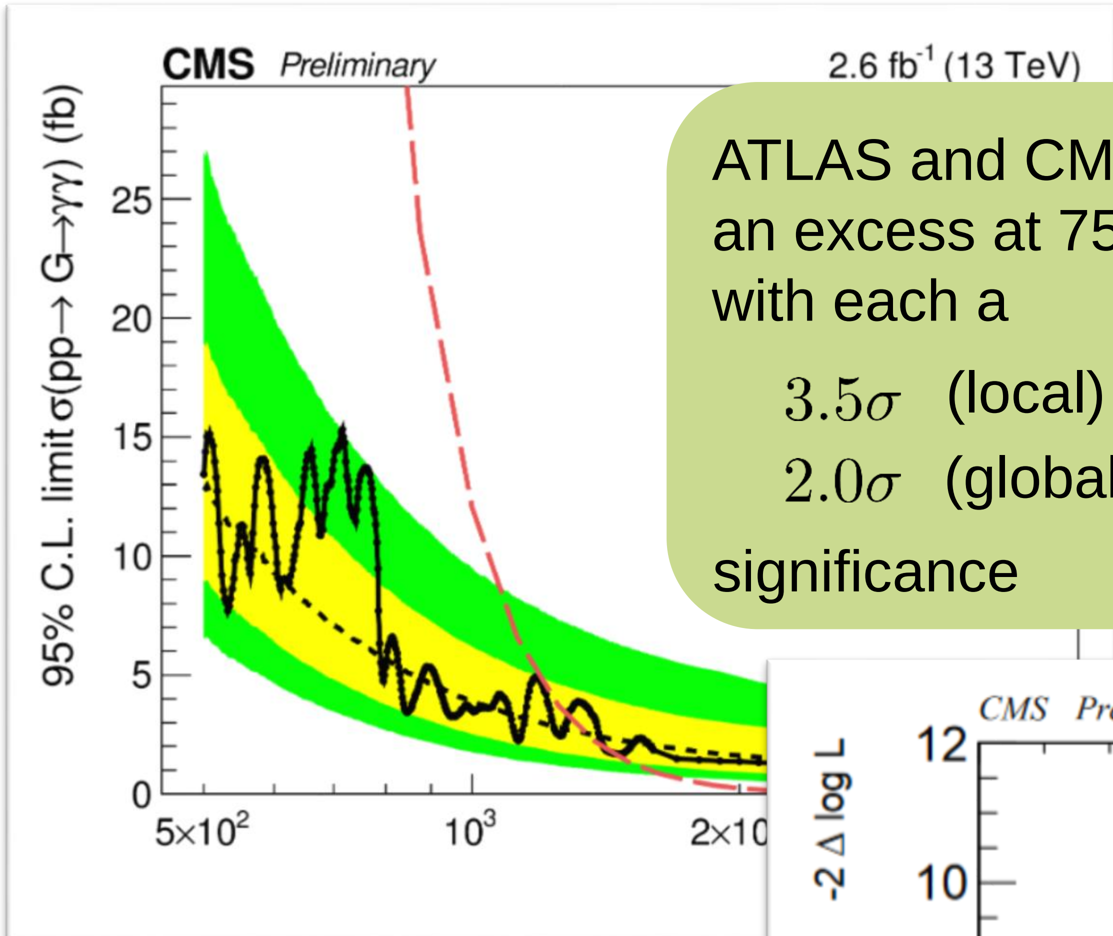
Institut Lagrange de Paris

UPMC SORBONNE UNIVERSITÉS

LPTHE Paris

cnrs dépasser les frontières

New Physics just around the Corner?

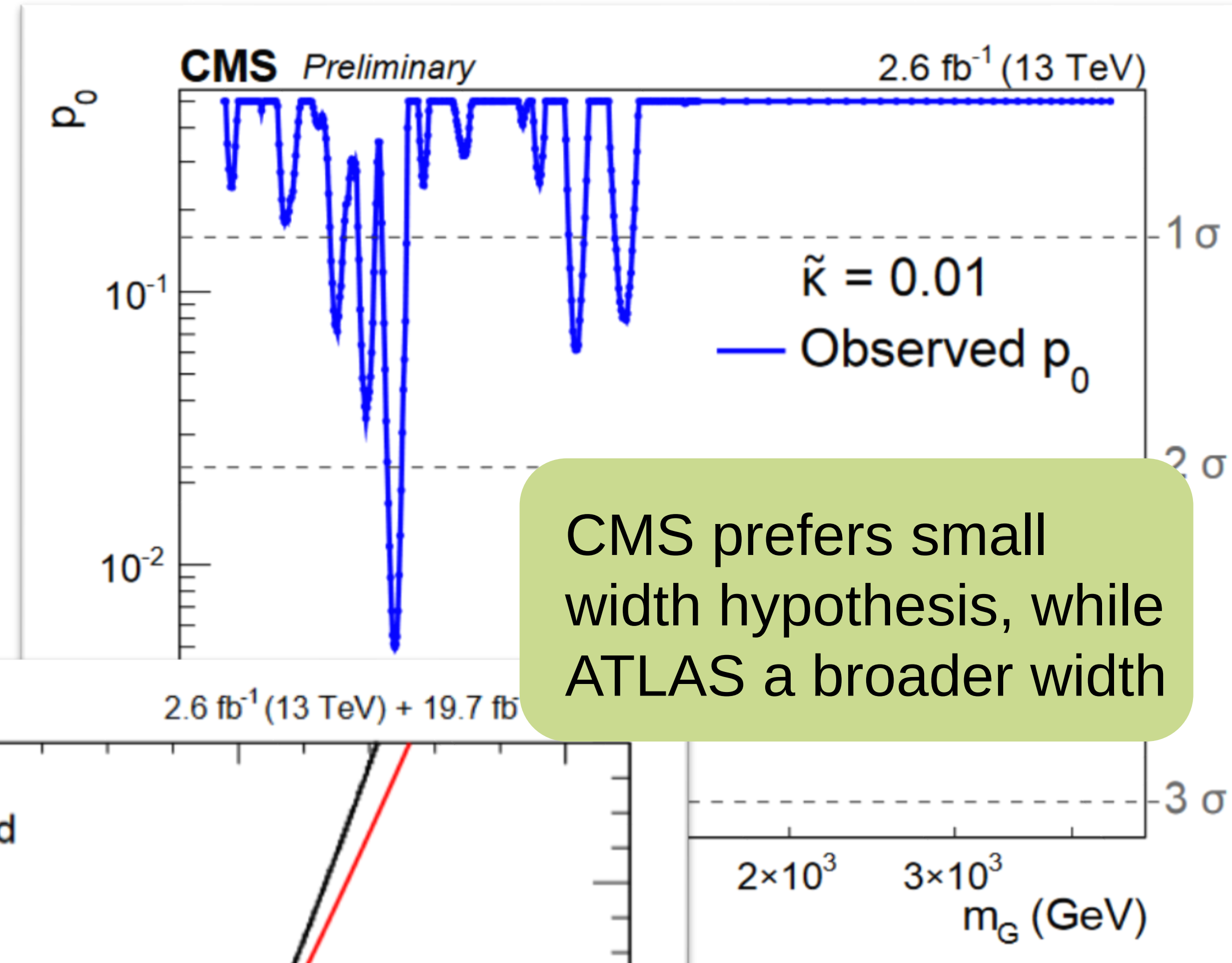


ATLAS and CMS report an excess at 750 GeV with each a

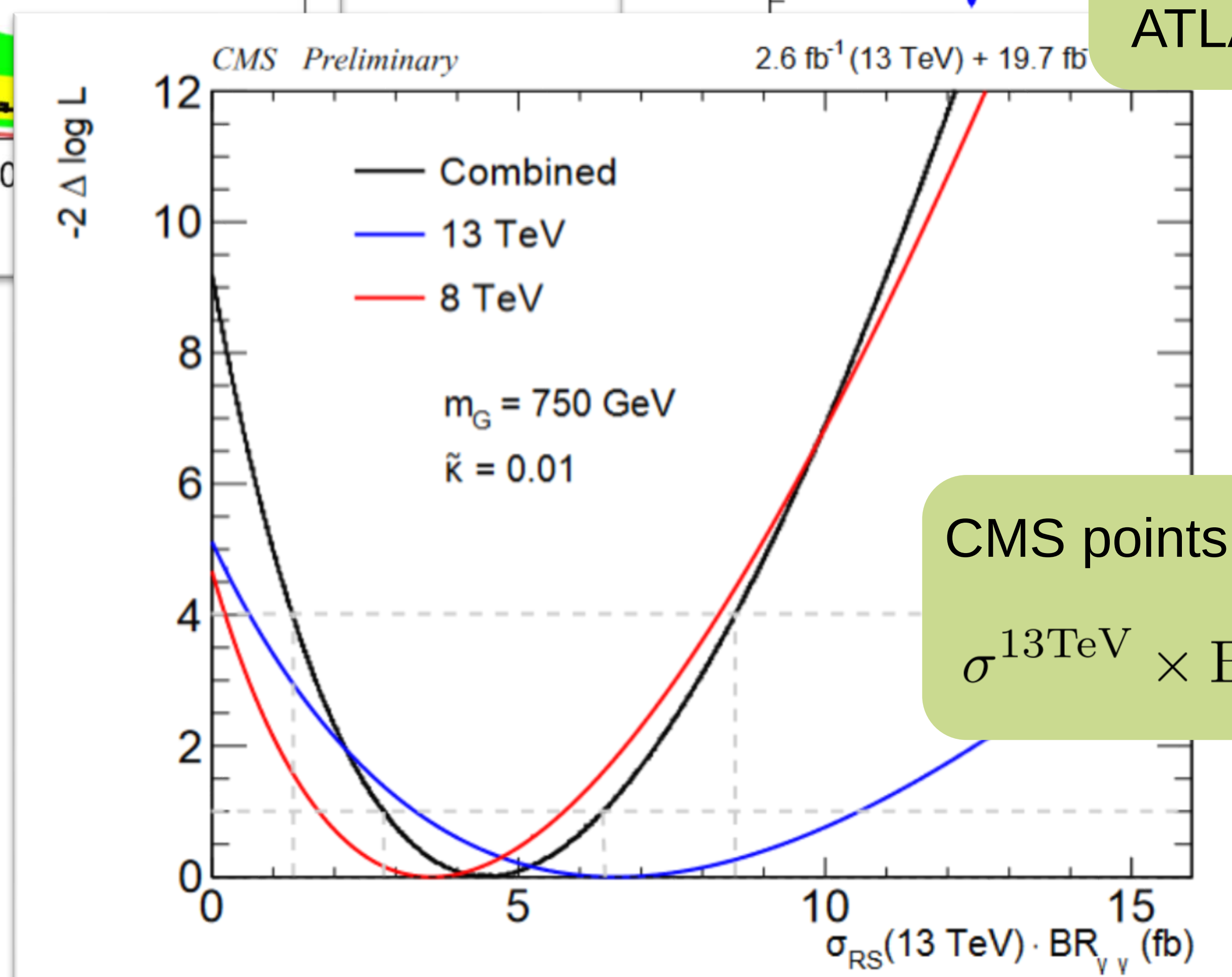
3.5σ (local)

2.0σ (global)

significance



CMS prefers small width hypothesis, while ATLAS a broader width



CMS points towards

$$\sigma^{13\text{TeV}} \times \text{BR} \approx (3.7 \pm 2)\text{fb}$$

Our Goal

- explain the Di-Photon Excess with a supersymmetric model
- maintain perturbativity up to the GUT scale
- no addition of “ad-hoc” fields
- compatible with current exclusion limits
- study taking into account sophisticated tools

→ SARAH/SPheno (one-loop masses, two-loop RGEs etc. ..)

Minimal Dirac Gaugino Model (MDGSSM)

MSSM + Dirac gaugino masses

- Extending MSSM particle content by Dirac gauginos **requires** **S**, **T** and $\mathbf{O_g}$ superfields in the adjoint representation of the gauge groups

$$W_{\mathrm{Diracgauginos}} = \int d^2\theta \sqrt{2}\theta^\alpha \left[m_{D1} \mathbf{S} W_{Y\,\alpha} + 2 m_{D2} tr(\mathbf{T} W_{2\,\alpha}) + 2 m_{D3} tr(\mathbf{O} W_{3\,\alpha}) \right]$$

- **Motivation**: preserving R-symmetry, ameliorate SUSY flavour problem, aid for naturalness, supersoft masses, supersafe from collider searches

⇒ **BUT**: natural unification of gauge couplings within the MSSM spoiled

- GUT unification by $(SU(3))^3$ gauge group

⇒ **Requires** extending particle content by
  - two Higgs-like doublets R_u and R_d
  - two pairs of vector-like right-handed electron superfields $E_{1,2}$ and $E'_{1,2}$

Minimal Dirac Gaugino Model (MDGSSM)

MSSM + Dirac gaugino masses + unification fields

- Extending MSSM particle content by Dirac gauginos **requires** **S**, **T** and $\mathbf{O_g}$ superfields in the adjoint representation of the gauge groups

$$W_{\text{Diracgauginos}} = \int d^2\theta \sqrt{2}\theta^\alpha \left[m_{D1}\mathbf{S}W_{Y\,\alpha} + 2m_{D2}tr(\mathbf{T}W_{2\,\alpha}) + 2m_{D3}tr(\mathbf{O}W_{3\,\alpha}) \right]$$

- **Motivation**: preserving R-symmetry, ameliorate SUSY flavour problem, aid for naturalness, supersoft masses, supersafe from collider searches

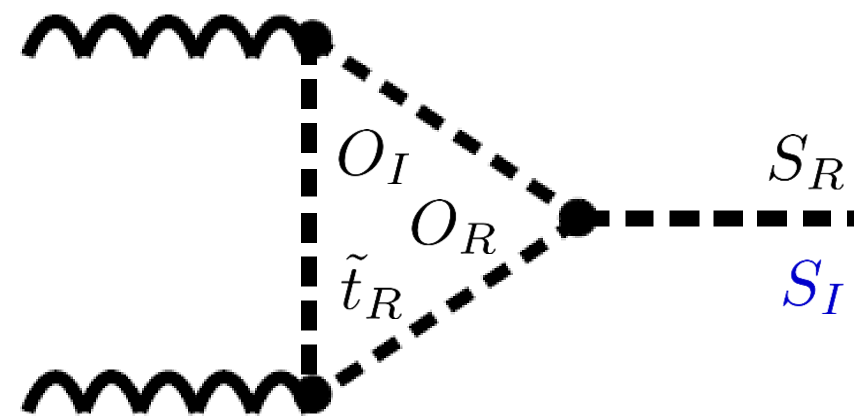
→ **BUT**: natural unification of gauge couplings within the MSSM spoiled

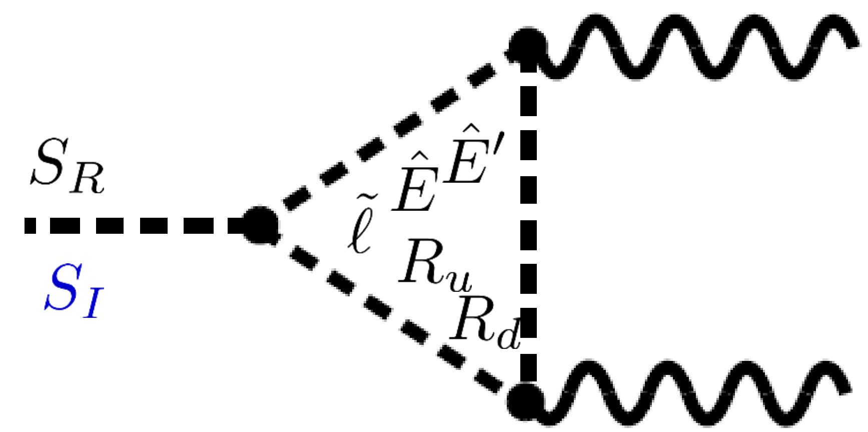
- GUT unification by $(SU(3))^3$ gauge group

→ **Requires** extending particle content by
  - two Higgs-like doublets R_u and R_d
  - two pairs of vector-like right-handed electron superfields $E_{1,2}$ and $E'_{1,2}$

MDGSSM- Particle Content

Names		Spin 0	Spin 1/2	Spin 1	$(SU(3), SU(2), U(1)_Y)$
Quarks	**Q**	$\tilde{Q} = (\tilde{u}_L, \tilde{d}_L)$	(u_L, d_L)		$(\mathbf{3},\ \mathbf{2},\ 1/6)$
	$\mathbf{U^c}$	$\tilde{U}^c_L$	U^c_L		$(\overline{\mathbf{3}},\ \mathbf{1},\ -2/3)$
(×3 families)	$\mathbf{D^c}$	$\tilde{D}^c_L$	D^c_L		$(\overline{\mathbf{3}},\ \mathbf{1},\ 1/3)$
Leptons	**L**	$(\tilde{\nu}_{eL}, \tilde{e}_L)$	(ν_{eL}, e_L)		$(\mathbf{1},\ \mathbf{2},\ -1/2)$
(×3 families)	$\mathbf{E^c}$	$\tilde{E}^c$	E^c		$(\mathbf{1},\ \mathbf{1},\ 1)$
Higgs	$\mathbf{H_u}$	(H_u^+, H_u^0)	$(\tilde{H}_u^+, \tilde{H}_u^0)$		$(\mathbf{1},\ \mathbf{2},\ 1/2)$
	$\mathbf{H_d}$	(H_d^0, H_d^-)	$(\tilde{H}_d^0, \tilde{H}_d^-)$		$(\mathbf{1},\ \mathbf{2},\ -1/2)$
Gluons	$\mathbf{W_{3\alpha}}$		$\lambda_{3\alpha}$ $[\equiv \tilde{g}_\alpha]$	g	$(\mathbf{8},\ \mathbf{1},\ 0)$
W	$\mathbf{W_{2\alpha}}$		$\lambda_{2\alpha}$ $[\equiv \tilde{W}^\pm, \tilde{W}^0]$	$W^\pm, W^0$	$(\mathbf{1},\ \mathbf{3},\ 0)$
B	$\mathbf{W_{1\alpha}}$		$\lambda_{1\alpha}$ $[\equiv \tilde{B}]$	B	$(\mathbf{1},\ \mathbf{1},\ 0\ )$
DG-octet	**O**	O	χ_g $[\equiv \tilde{g}']$		$(\mathbf{8},\ \mathbf{1},\ 0)$
DG-triplet	**T**	$\{T^0, T^\pm\}$	$\{\chi_T^0, \chi_T^\pm\}$ $[\equiv \{\tilde{W}'^\pm, \tilde{W}'^0\}]$		$(\mathbf{1},\mathbf{3},\ 0\ )$
DG-singlet	**S**	S	χ_S $[\equiv \tilde{B}']$		$(\mathbf{1},\ \mathbf{1},\ 0\ )$
Higgs-like Leptons	$\mathbf{R_u}$	R_u	$\tilde{R}_u$		$(\mathbf{1},\ \mathbf{2},\ -1/2)$
	$\mathbf{R_d}$	R_d	$\tilde{R}_d$		$(\mathbf{1},\ \mathbf{2},\ 1/2)$
Fake electrons	$\hat{\mathbf{E}}(\times 2)$	$\hat{E}$	$\tilde{\hat{E}}$		$(\mathbf{1},\ \mathbf{1},1)$
	$\hat{\mathbf{E}}'(\times 2)$	$\hat{E}'$	$\tilde{\hat{E}}'$		$(\mathbf{1},\ \mathbf{1},-1)$





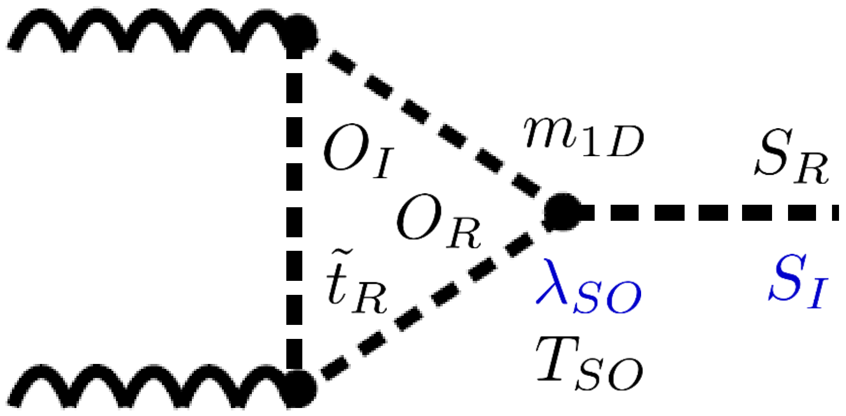
"fake leptons"

"fake electrons"

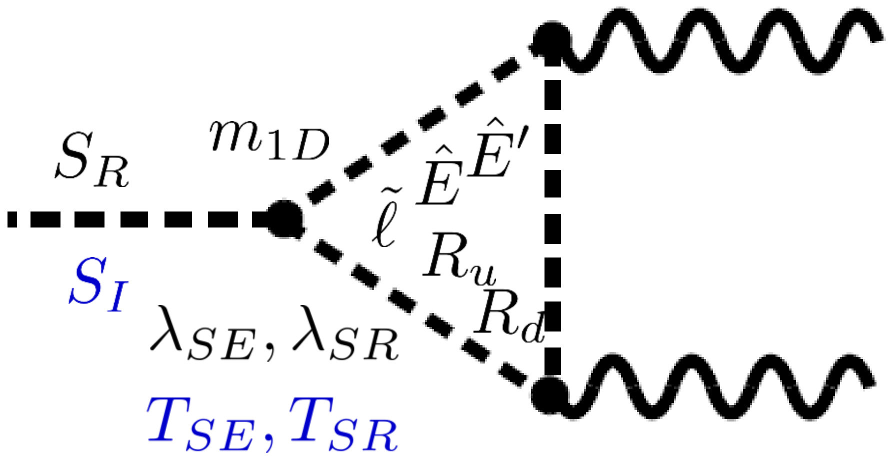
Minimal Dirac Gaugino Model

$$W = W_{Yukawa} + W_{DG} + W_{RV}$$

$$W_{Yukawa} = Y_u^{ij}\mathbf{U^c}_i\mathbf{Q}_j\mathbf{H}_u - Y_d^{ij}\mathbf{D^c}_i\mathbf{Q}_j\mathbf{H}_d - Y_e^{ij}\mathbf{E^c}_i\mathbf{L}_j\mathbf{H_d}$$



$$\begin{aligned} W_{DG} &= (\mu + \lambda_S \mathbf{S})\mathbf{H_d}\mathbf{H_u} + \sqrt{2}\lambda_T \mathbf{H_d}\mathbf{T}\mathbf{H_u} \\ &+ (\mu_R + \lambda_{SR}\mathbf{S})\mathbf{R_u}\mathbf{R_d} + 2\lambda_{TR}\mathbf{R_u}\mathbf{T}\mathbf{R_d} \\ &+ (\mu_{\hat{E}\,ij} + \lambda_{S\hat{E}^c\,ij}\mathbf{S})\hat{\mathbf{E}}_i\hat{\mathbf{E}}'_j + \lambda_{SEij}\mathbf{S}\mathbf{E^c}_i\hat{\mathbf{E}}'_j \end{aligned}$$

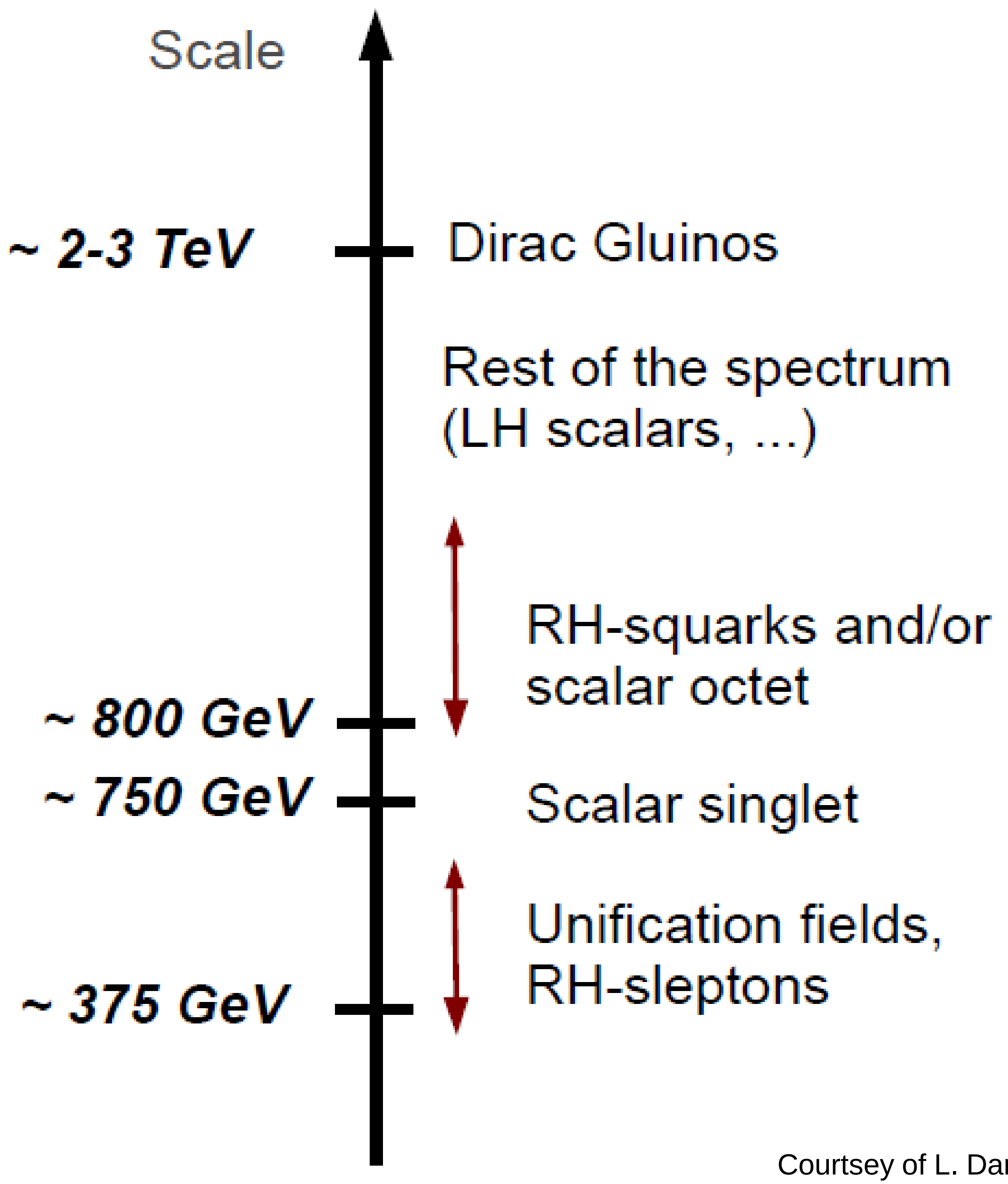


$$\begin{aligned} W_{RV} &= L\mathbf{S} + \frac{\hat{M}_1}{2}\mathbf{S}^2 + \frac{\kappa}{3}\mathbf{S}^3 + \hat{M}_2\mathrm{tr}(\mathbf{TT}) + \hat{M}_3\mathrm{tr}(\mathbf{OO}) \\ &+ \lambda_{ST}\mathbf{S}\mathrm{tr}(\mathbf{TT}) + \lambda_{SO}\mathbf{S}\mathrm{tr}(\mathbf{OO}) + \frac{\kappa_O}{3}\mathrm{tr}(\mathbf{OOO}) \end{aligned}$$

$$-\Delta\mathcal{L}^{\text{scalar soft}}_{\text{trilinear}} = +T_{SE}^{ij}S\hat{E}_i\hat{E}'_j + T_{SR}SR_dR_u + T_{SO}S\mathrm{tr}(O^2) + h.c.$$

When preserving R-symmetry, (λ_{SE}, T_{SE}) and (λ_{SO}, T_{SO}) are not allowed simultaneously

Minimal Dirac Gaugino Model



Courtsey of L. Darme

Constraints from Higgs mixing and LHC8

Scalar singlet mix with SM Higgs:

$$\{h, H, S_R, T_R^0\}$$

$$\begin{pmatrix} M_Z^2 + \Delta_h s_{2\beta}^2 & \Delta_h s_{2\beta} c_{2\beta} & \Delta_{hS} & \Delta_{hT} \\ \Delta_h s_{2\beta} c_{2\beta} & M_A^2 - \Delta_h s_{2\beta}^2 & \Delta_{HS} & \Delta_{HT} \\ \Delta_{hS} & \Delta_{HS} & \tilde{m}_S^2 & \lambda_S \lambda_T \frac{v^2}{2} \\ \Delta_{hT} & \Delta_{HT} & \lambda_S \lambda_T \frac{v^2}{2} & \tilde{m}_T^2 \end{pmatrix}$$

Singlet admixture of SM Higgs given by

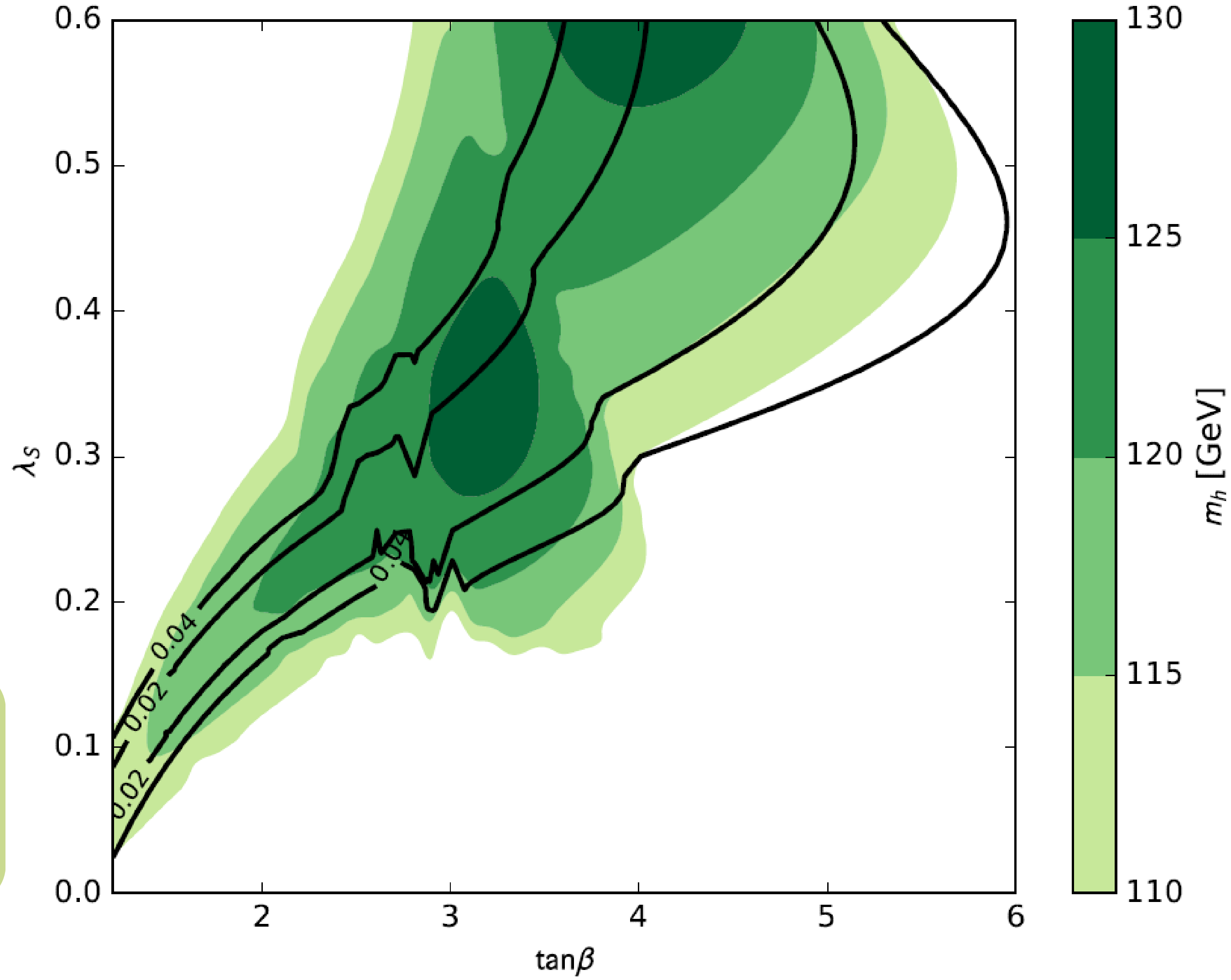
$$\begin{aligned} \Delta_{hS} &= v[v_S \lambda_S^2 - g' m_{1D} c_{2\beta} + \sqrt{2}\lambda_S \mu + \lambda_S \lambda_T v_T] \\ &= v[\sqrt{2}\lambda_S \tilde{\mu} - g' m_{1D} c_{2\beta}] \end{aligned}$$

Bounds on decays into hh, ZZ, WW from LHC8 searches constrain allowed mixing of the SM Higgs boson with the scalar singlet

$$\frac{\Gamma(S \to hh)}{\Gamma(S \to \gamma\gamma)} \simeq \frac{0.1 \times |S_{13}|^2 m_{SR}}{\Gamma(S \to \gamma\gamma)} < 50$$

$$\frac{\Gamma(S \to ZZ)}{\Gamma(S \to \gamma\gamma)} \simeq \frac{0.09 \times |S_{13}|^2 m_{SR}}{\Gamma(S \to \gamma\gamma)} < 15$$

$$\frac{\Gamma(S \to WW)}{\Gamma(S \to \gamma\gamma)} \simeq \frac{0.17 \times |S_{13}|^2 m_{SR}}{\Gamma(S \to \gamma\gamma)} < 50$$



SM Higgs mass bounded by

$$m_h^2 < M_Z^2 c_{2\beta}^2 + \frac{v^2}{2}(\lambda_S^2 + \lambda_T^2) s_{2\beta}^2$$

ideally lower m_{1D} and μ
moderate λ_S and λ_T

Rho-parameter & Naturalness

The Triplet with vev v_t contributes to the W-boson mass and is, thus, constrained by the ρ - parameter

$$\rho \equiv \frac{M_W^2}{c_{\theta_W}^2 M_Z^2} = 1 + \Delta\rho \sim 1 + \frac{4v_T^2}{v^2}$$

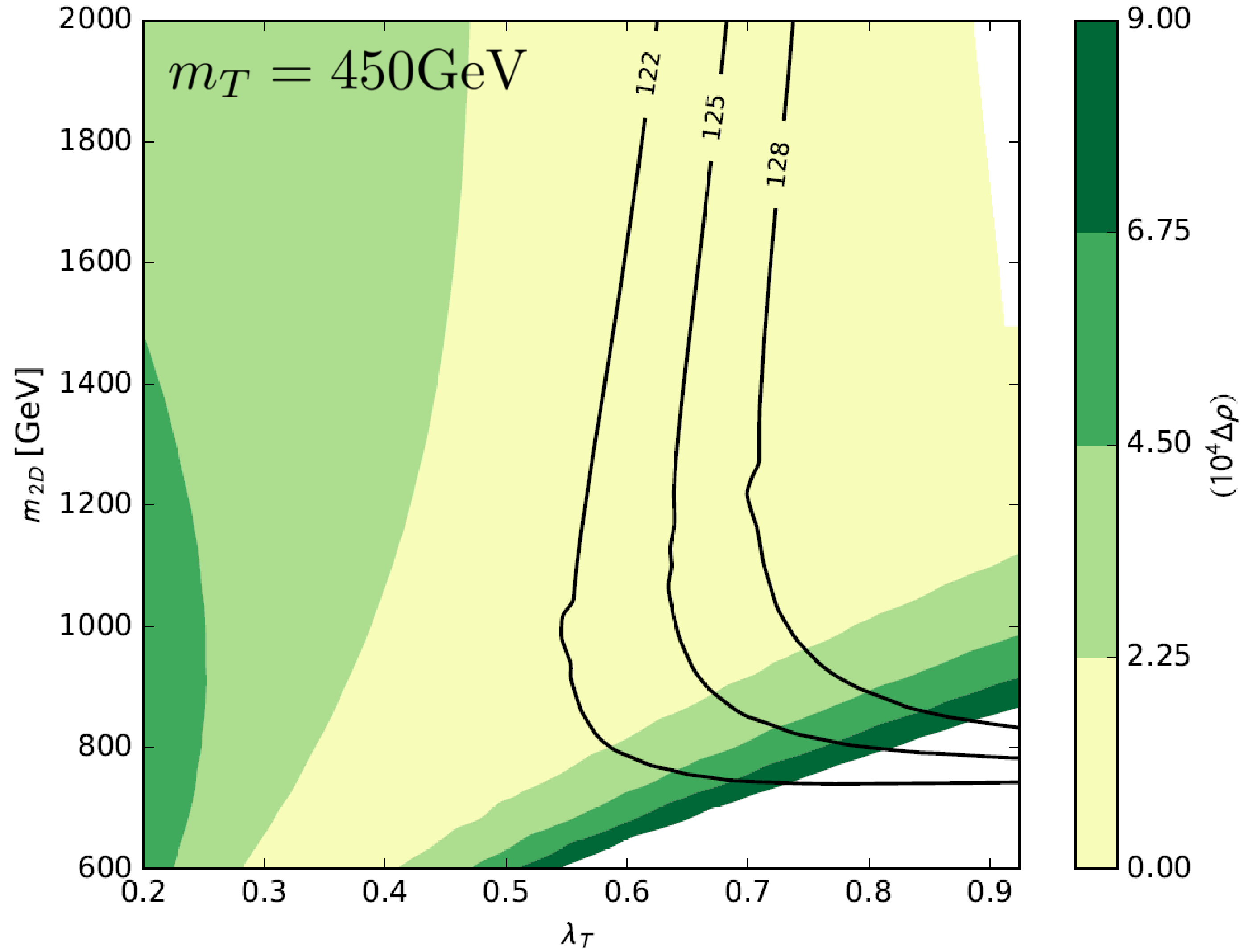
$$v_T \simeq \frac{v^2(-g m_{2D} c_{2\beta} - \sqrt{2}\tilde{\mu}\lambda_T)}{2(m_T^2 + 4m_{2D}^2 + B_T)}$$

Triplet scalars induce radiative corrections to $m_{H_{u,d}}^2$

$$\delta m_{H_{u,d}}^2 \supset -\frac{1}{16\pi^2}(2\lambda_T^2 m_T^2)\log\left\{\frac{\Lambda}{\text{TeV}}\right\}$$

For fine-tuning of less than 10% we arrive at the condition for the soft triplet mass:

$$m_T < \frac{1}{\lambda_T} 450 \text{ GeV}$$



$$\Delta\rho < (4.2 \pm 2.7) \times 10^{-4}$$

ideally larger soft masses and larger m_{2D} while not having a too large triplet mass m_T

Constraints on Colour Octets

$$O^{(a)} = \frac{O_R^{(a)} + iO_I^{(a)}}{\sqrt{2}}$$

- Octets decay only to gluons and quarks
- leading to possible signatures of four jets, dijet/ditop and four tops

13 TeV four top search [ATLAS-CONF-2016-013] sets with 140 fb the most stringent constraint

$$\Gamma(O_2 \to gg) = \frac{5\alpha_s^3}{192\pi^2}\frac{m_{D3}^2}{M_{O_2}}\sin^2(\frac{\phi_{\tilde{B}}}{2})|\lambda_{g_2}|^2$$

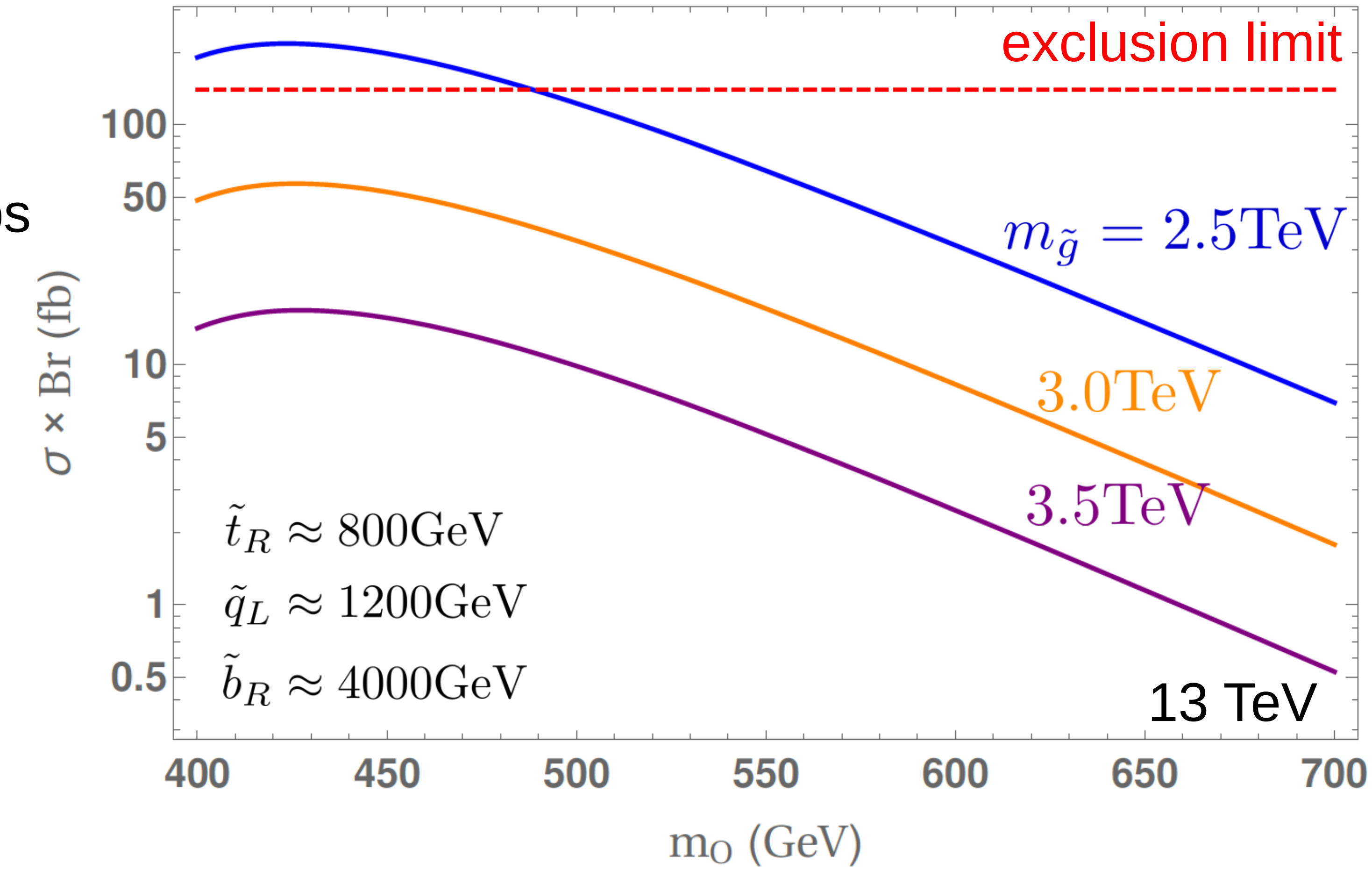
pseudo-scalar octet decays entirely into tops

restricts pseudo-scalar octet mass to be heavier than 880 GeV

$$\Gamma(O_1 \to gg) = \frac{5\alpha_s^3}{192\pi^2}\frac{m_{D3}^2}{M_{O_1}}\cos^2(\frac{\phi_{\tilde{B}}}{2})|\lambda_{g_1}|^2$$

scalar octet decays into gluons and quarks

no constraints on scalar octet mass for gluinos heavier than 3 TeV



Perturbativity and Landau Poles

Numerical check if gauge couplings remain perturbative at two-loops up to the GUT scale

$$\beta_{\lambda_S} = \frac{1}{16\pi^2}\lambda_S[4\lambda_S^2 + 3\lambda_T^2 + 2\lambda_{SR}^2 + 2\lambda_{SE}^2 + 4\lambda_{SO}^2 - \frac{3}{5}g_1^2 - 3g_2^2 + 3y_t^2 + \ldots]$$

fixed by Higgs mixing

$$\beta_{\lambda_T} = \frac{1}{16\pi^2}\lambda_T[2\lambda_S^2 + 4\lambda_T^2 - \frac{3}{5}g_1^2 - 7g_2^2 + 3y_t^2 \ldots]$$

large value aimed for Higgs mass

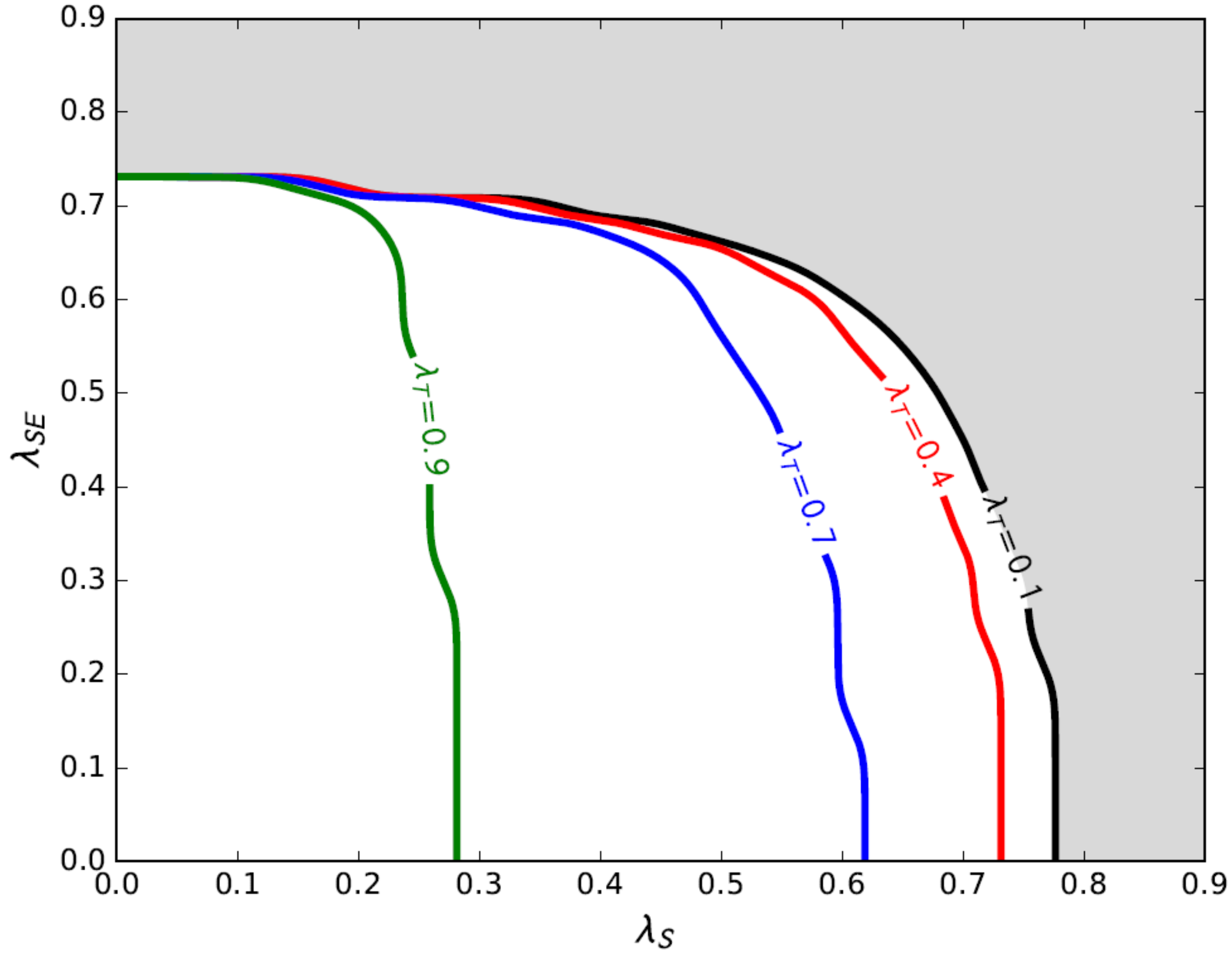
$$\beta_{\lambda_{SE}} = \frac{1}{16\pi^2}\lambda_{SE}[2\lambda_S^2 + 4\lambda_{SE}^2 + 2\lambda_{SR}^2 + 4\lambda_{SO}^2 - \frac{12}{5}g_1^2 + \ldots]$$

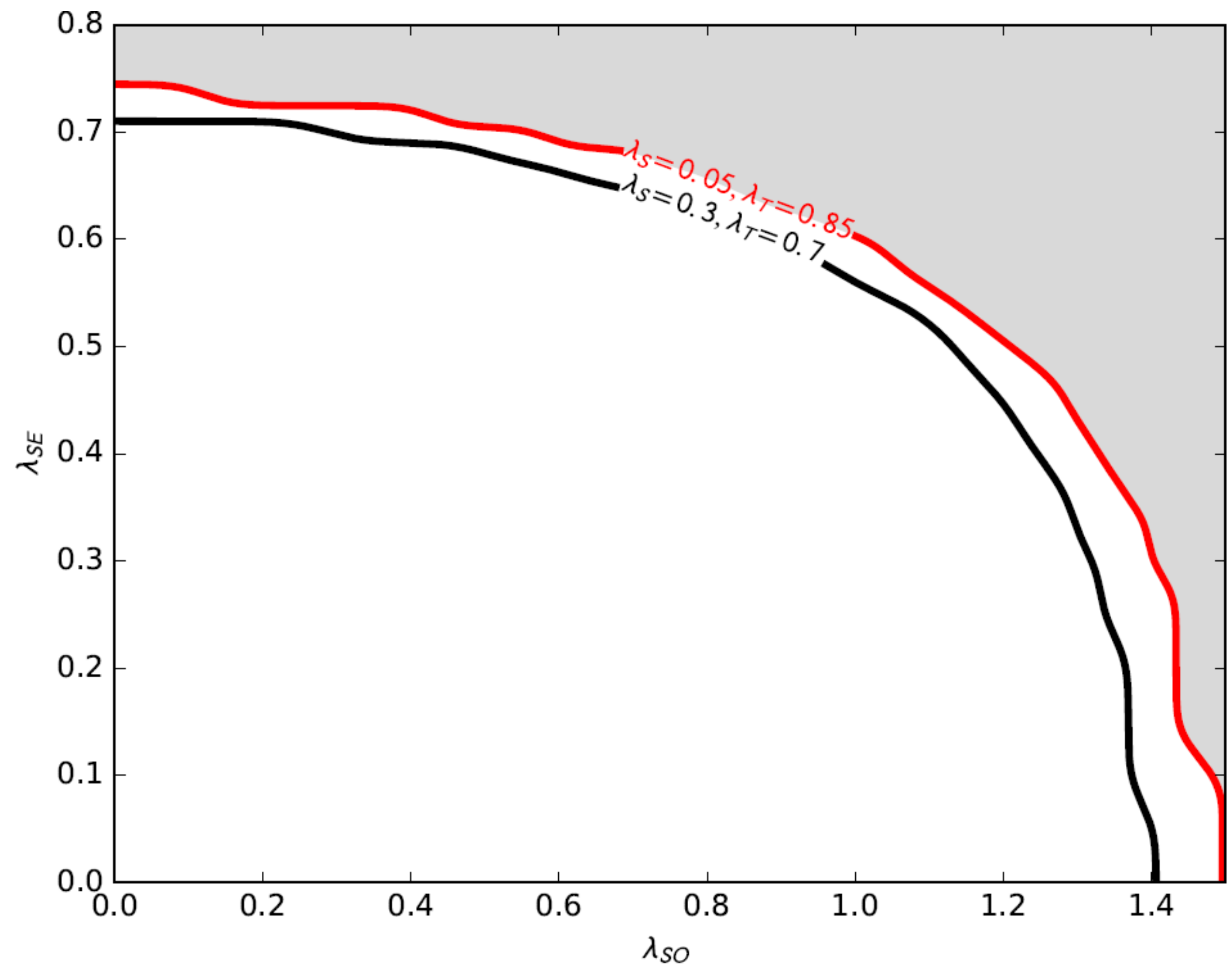
$$\beta_{\lambda_{SR}} = \frac{1}{16\pi^2}\lambda_{SR}[2\lambda_S^2 + 2\lambda_{SE}^2 + 4\lambda_{SR}^2 + 4\lambda_{SO}^2 - \frac{3}{5}g_1^2 - 3g_2^2 + \ldots]$$

large values favoured for increasing decay to photons

$$\beta_{\lambda_{SO}} = \frac{1}{16\pi^2}\lambda_{SO}[2\lambda_S^2 + 4\lambda_{SE}^2 + 2\lambda_{SR}^2 + 6\lambda_{SO}^2 - 12g_3^2 + \ldots]$$

only present in RV scenarios, stabilises potential for having larger T_{SO}





Charge and Colour breaking Minima

Including large trilinears makes a check for vacuum stability essential:

Charge breaking vacua

$$T_{SE}(S\hat{E}\hat{E}' + h.c.)$$

$$\lambda_{SE}^2|\hat{E}'\hat{E}|^2$$

$$\frac{T_{SE}^2}{\lambda_{SE}^2} > 2m_{ER}^2 + m_{SR}^2 + 2\sqrt{2}m_{ER}m_{SR}$$

$$m_{SR}^2 \equiv m_S^2 + B_S + 4m_{DY}^2$$
$$m_{ER}^2 \equiv m_{\hat{E}}^2 + m_{\hat{E}'}^2 + 2B_E + 2\mu_E^2$$

Stringent bound on T_{SE}

Color breaking vacua

$$T_{SO}(S\,\mathrm{tr}(OO) + h.c.)$$ Destabilising trilinears

$$\lambda_{SO}^2|\mathrm{tr}(OO)|^2$$ Stabilising quartics

In R-symmetric case, T_{SO} crucial for coupling of S with scalar octet; no quartic terms, assume additional quartics are loop induced

$$\frac{\lambda_O}{4}|O^a|^4 + \lambda_{SO}^H|S|^2|O^a|^2$$

$$T_{SO}^2 > \left(2\sqrt{\lambda_{SO}^H + \lambda_{SO}^2}\,m_{OR} + \sqrt{\lambda_O + \lambda_{SO}^2}\,m_{SR}\right)^2$$

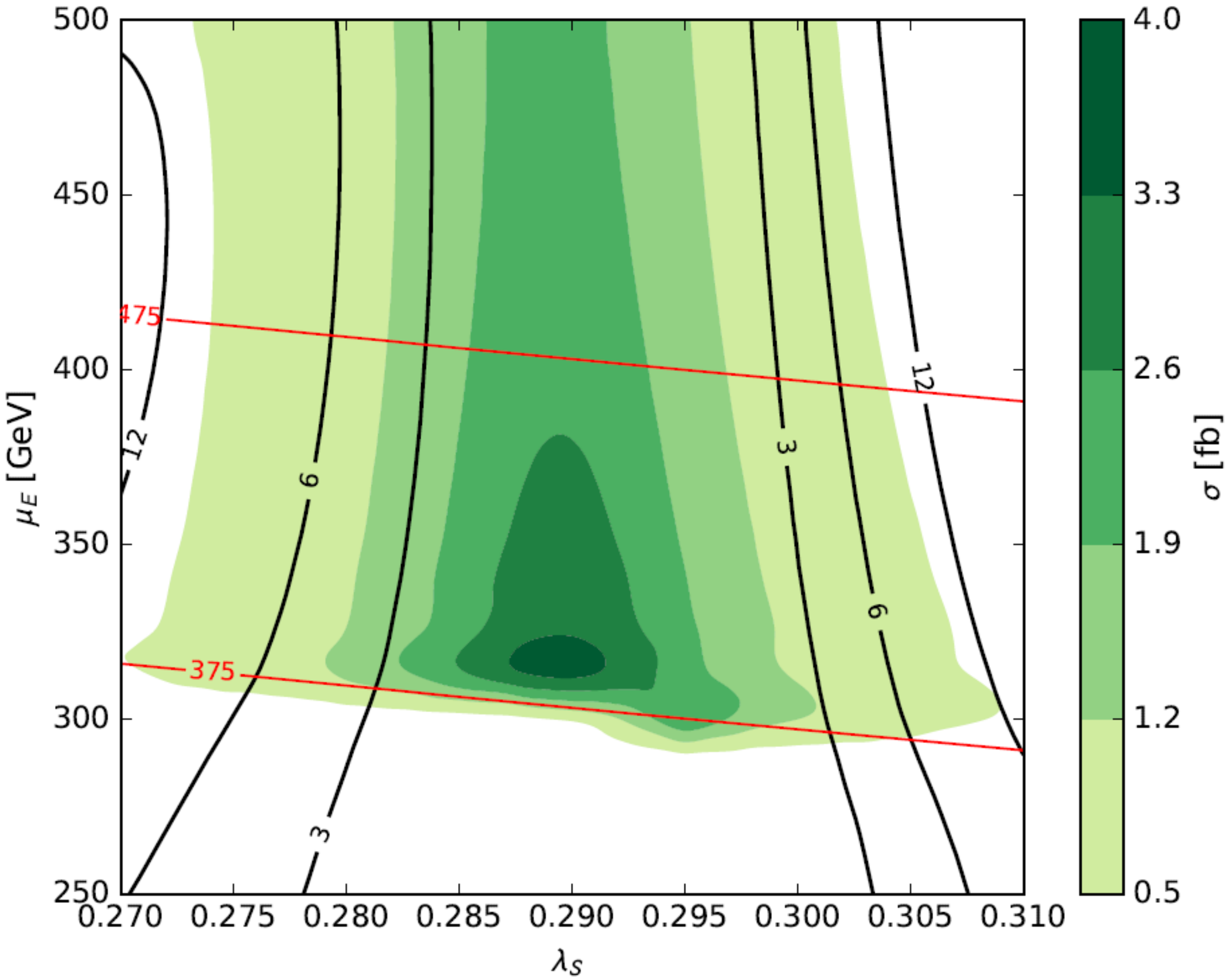
$$m_{OR}^2 \equiv m_O^2 + B_O + 4|m_{D3}|^2$$

$\lambda_O, \lambda_{SO}^H \approx \mathcal{O}(0.04)$ → $T_{SO} < 310\,\mathrm{GeV}$

In R-violating case, allows for larger T_{SO}

R-symmetry conserving Scenarios

Gluon fusion induced by light squarks

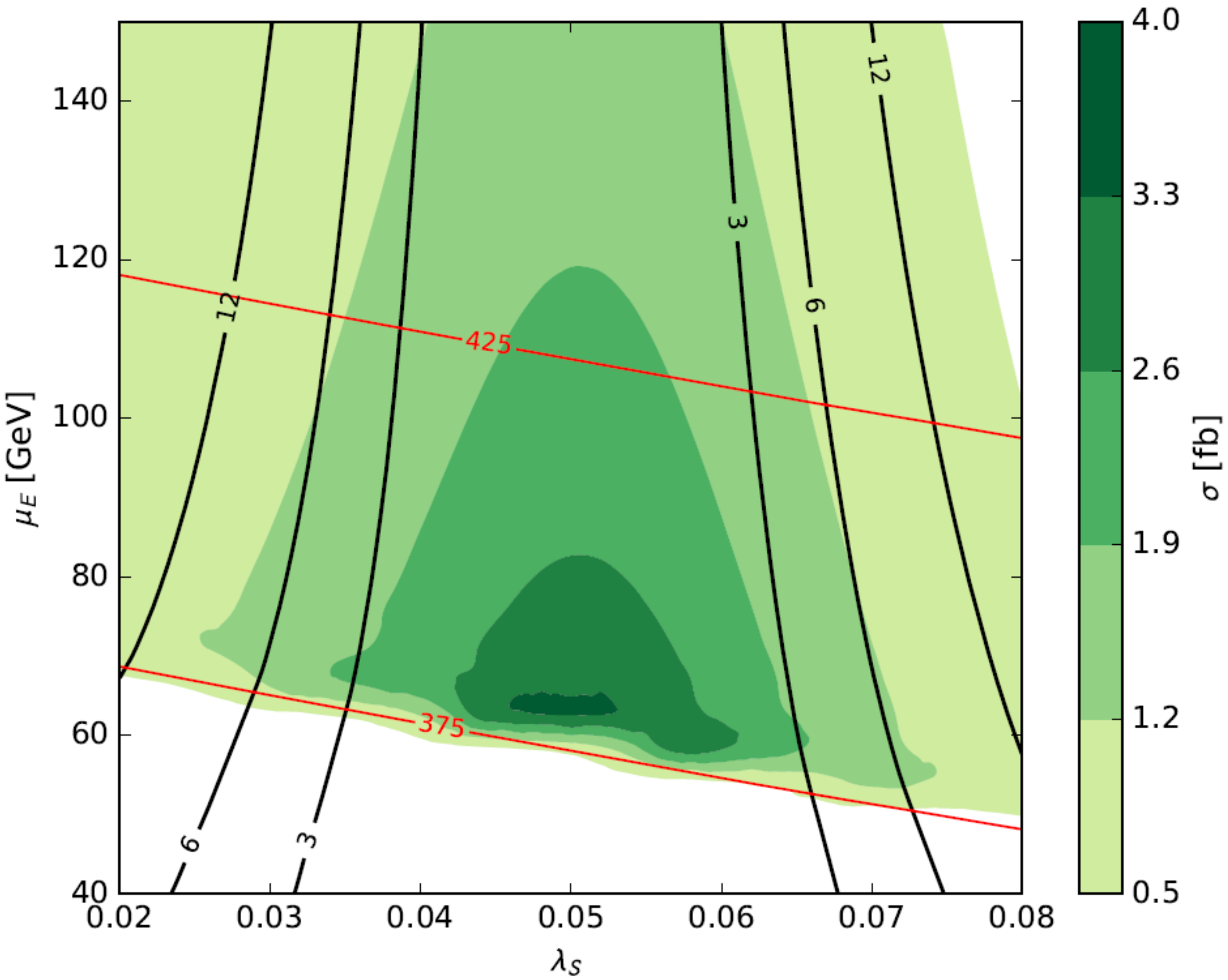


	Parameter	$\mathbf{R_a}$	$\mathbf{R_b}$
Higgs mass	μ	925 GeV	450 GeV
	$\tan\beta$	3	5
	λ_T	0.7	0.85
	m_T	500 GeV	1000 GeV
Singlet masses and mixing	m_{1D}	1250 GeV	100 GeV
	m_S	500 GeV	775 GeV
	B_S	-2.44^2 TeV^2	-200^2 GeV^2
	λ_S	0.29	0.05
Singlet decay /production amplitude to gg	T_{SO}	200 GeV	300 GeV
	m_O	1300 GeV	1025 GeV
	$m_{\tilde{t}_R}$	500 GeV	1200 GeV
Singlet decay amplitude to $\gamma\gamma$	$\lambda_{SR} = \lambda_{SE}$	0.7	0.7
	$m_E^2 = m_{R_{u,d}}^2$	10^2 GeV^2	150^2 GeV^2
	$\mu_E = \mu_{R_{u,d}}/1.4$	325 GeV	65 GeV
	$m_{\tilde{l}R}$	250 GeV	500 GeV
Outputs	m_h	125.5 GeV	124.9 GeV
	m_{S_R}	750.1 GeV	755.7 GeV
	m_{O_I}/m_{O_R} ($\mathbf{R_a}$ /$\mathbf{R_b}$)	945.5 GeV	390.0 GeV
	$m_{\tilde{t}_R}$	820.3 GeV	1165.0 GeV
	$m_{\tilde{l}_R}$	418 GeV	513 GeV
	$m_{\tilde{\hat{E}}}$	397 GeV	382 GeV
	$\sigma(S \to \gamma\gamma)$	**3.20 fb**	**3.18 fb**
	$\Delta\rho$	0.97×10^{-4}	3.17×10^{-4}

- R-symmetric case: no trilinears T_{SE}, T_{SR}
- Gluon fusion induced by light squark loops enhanced du to large m_{1D}
- Photon decay via loops of (fake) sleptons and fake fermions $m_{1D}, \lambda_{SE}, \lambda_{SR}$
- large negative B_S for a scalar singlet mass of 750 GeV
- not (strongly) constrained by LHC8 data

R-symmetry conserving Scenarios

Gluon fusion induced by scalar octets



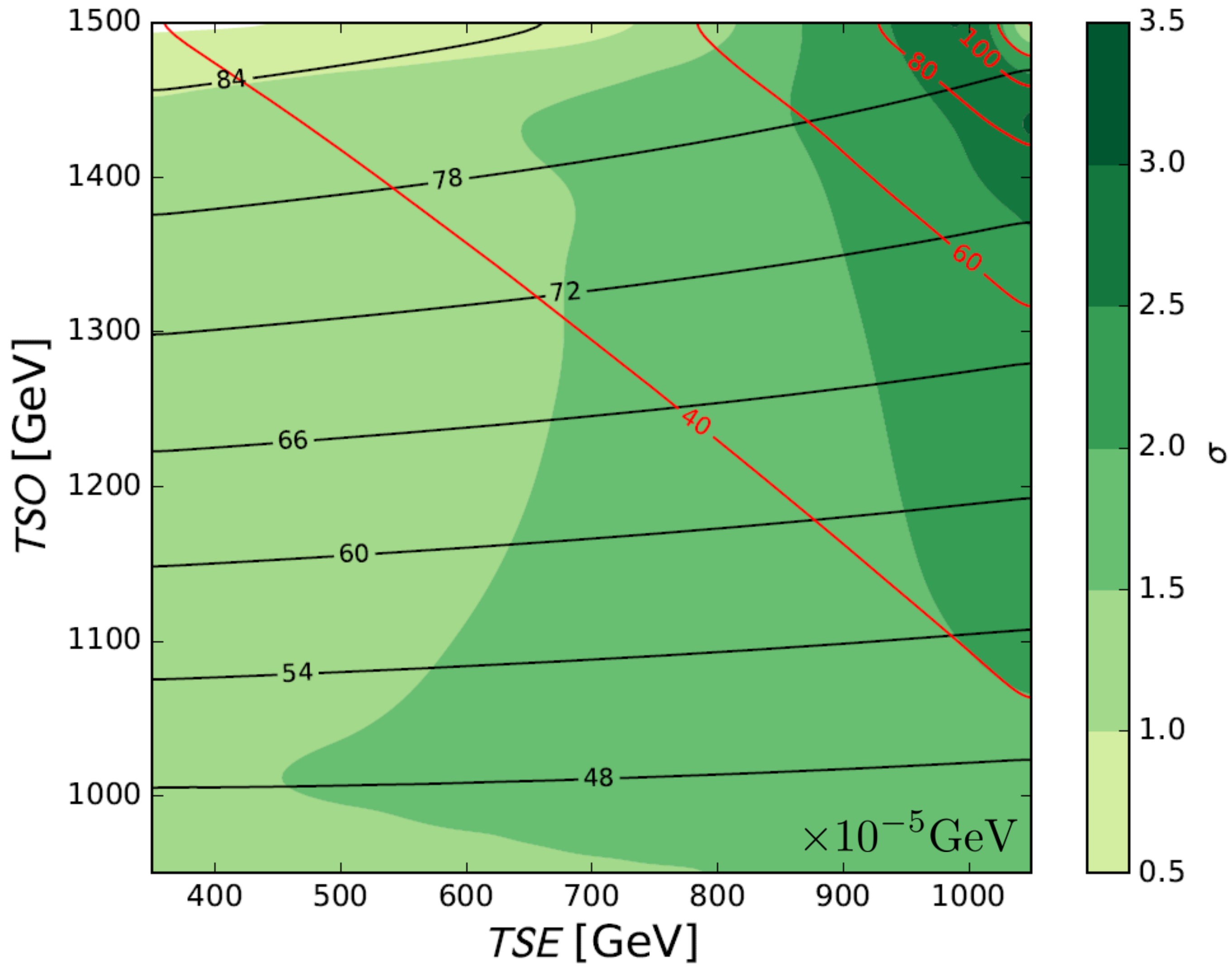
	Parameter	$\mathbf{R_a}$	$\mathbf{R_b}$
Higgs mass	μ	925 GeV	450 GeV
	$\tan\beta$	3	5
	λ_T	0.7	0.85
	m_T	500 GeV	1000 GeV
Singlet masses and mixing	m_{1D}	1250 GeV	100 GeV
	m_S	500 GeV	775 GeV
	B_S	-2.44^2 TeV^2	-200^2 GeV^2
	λ_S	0.29	0.05
Singlet decay /production amplitude to gg	T_{SO}	200 GeV	300 GeV
	m_O	1300 GeV	1025 GeV
	$m_{\tilde{t}_R}$	500 GeV	1200 GeV
Singlet decay amplitude to $\gamma\gamma$	$\lambda_{SR} = \lambda_{SE}$	0.7	0.7
	$m_E^2 = m_{R_{u,d}}^2$	10^2 GeV^2	150^2 GeV^2
	$\mu_E = \mu_{R_{u,d}}/1.4$	325 GeV	65 GeV
	$m_{\tilde{l}R}$	250 GeV	500 GeV
Outputs	m_h	125.5 GeV	124.9 GeV
	m_{S_R}	750.1 GeV	755.7 GeV
	m_{O_I}/m_{O_R} ($\mathbf{R_a}$ / $\mathbf{R_b}$)	945.5 GeV	390.0 GeV
	$m_{\tilde{t}_R}$	820.3 GeV	1165.0 GeV
	$m_{\tilde{l}_R}$	418 GeV	513 GeV
	$m_{\tilde{\tilde{E}}}$	397 GeV	382 GeV
	$\sigma(S \to \gamma\gamma)$	**3.20 fb**	**3.18 fb**
	$\Delta\rho$	0.97×10^{-4}	3.17×10^{-4}

- R-symmetric case: no trilinears T_{SE}, T_{SR}
- Gluon fusion induced by light scalar octets having large m_{3D}, and thus larger negative B_O
- Photon decay via loops of fake sleptons and fake fermions $\lambda_{SE}, \lambda_{SR}$
- No photon decay induced via sleptons anymore (small m_{1D}) → less tuning in λ_S, B_S

- not (strongly) constrained by LHC8 data

R-symmetry violating Scenarios

Gluon fusion induced by pseudo-scalar octets

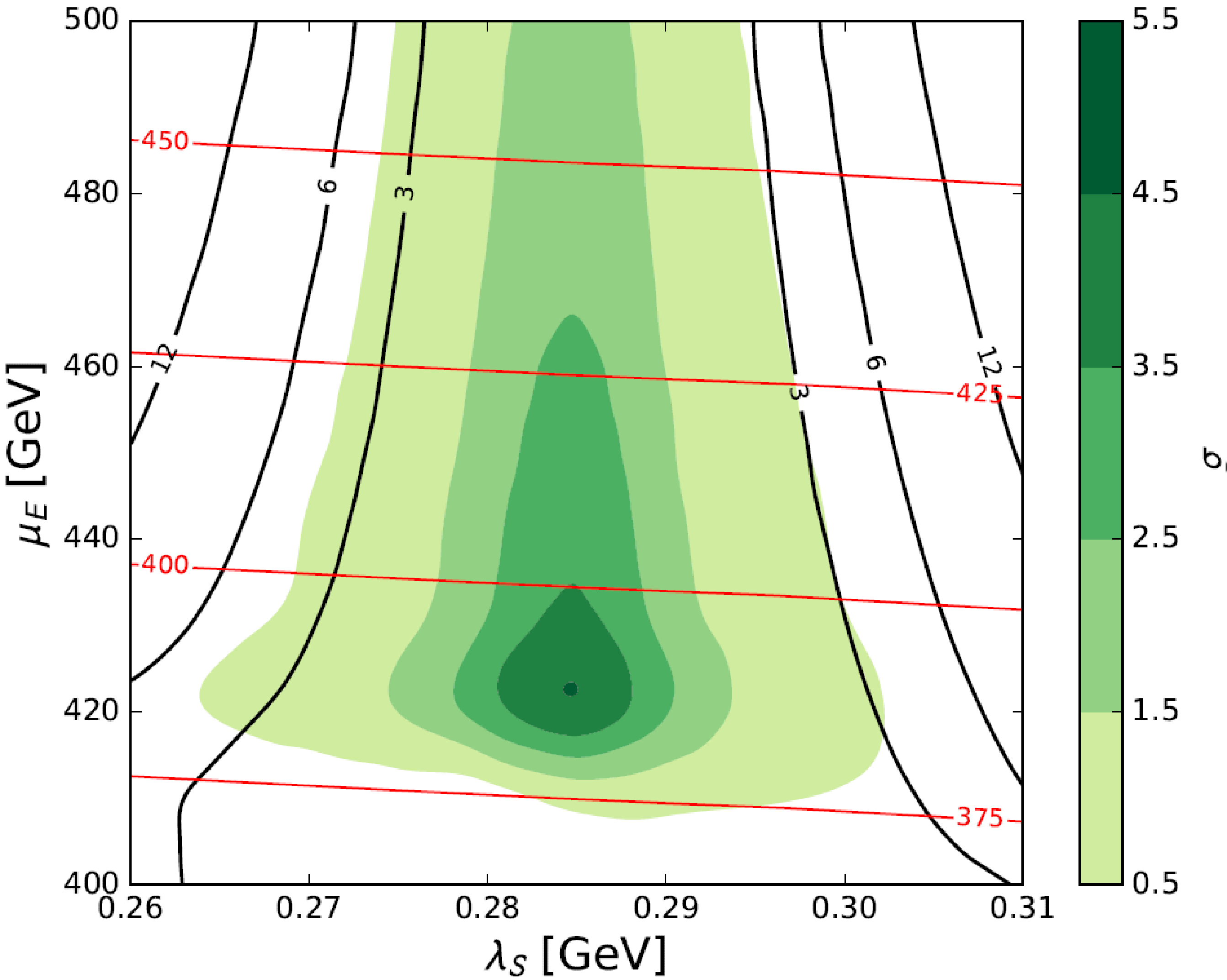


- allow $T_{SE} = T_{SR}$ while having $\lambda_{SE} = \lambda_{SR}$
- allow λ_{SO} and thus larger values for T_{SO}

→ increase of production via gluons as well as decay into photons

$\tan\beta$	2	4
μ	660 GeV	450 GeV
m_S	490 GeV	310 GeV
m_T	1250 GeV	1200 GeV
m_O	530 GeV	890 GeV
M_3	0	1400 GeV
m_{1D}	1250 GeV	490 GeV
m_{2D}	1000 GeV	1000 GeV
m_{3D}	1600 GeV	2300 GeV
λ_S	0.29	0.27
λ_T	0.65	0.70
λ_{SO}	0.65	0.65
$\lambda_{SR} = \lambda_{SE}$	0.65	0.65
B_S	-2.4^2 TeV^2	-0.7^2 TeV^2
$T_{SE} = T_{SR}$	-1000 GeV	0 GeV
T_{SO}	1500 GeV	600 GeV
m_h	124.8 GeV	125.9 GeV
m_{S_R}	755.7 GeV	756.5 GeV
m_{S_I}	1125.1 GeV	751.0 GeV
m_{O_I}	886.3 GeV	886.3 GeV
m_E	382.2 GeV	386.7 GeV
$m_{\tilde{E}}$	378.6 GeV	377.2 GeV
$m_{\tilde{t}_1}$	1776.5 GeV	1597.2 GeV
$m_{\tilde{g}}$	1825.8 GeV	1916.0 GeV
ZZ	0.1	0.0
hh	0.5	1.2
WW	0.3	0.0
gg	0.7	4.4
$\Delta\rho$	9.9×10^{-5}	2.4×10^{-4}
$\sigma(S \to \gamma\gamma)$	**3.1 fb**	**4.4 fb**

Gluon fusion induced by pseudo-scalar octets



$\tan\beta$	2	4
μ	660 GeV	450 GeV
m_S	490 GeV	310 GeV
m_T	1250 GeV	1200 GeV
m_O	530 GeV	890 GeV
M_3	0	1400 GeV
m_{1D}	1250 GeV	490 GeV
m_{2D}	1000 GeV	1000 GeV
m_{3D}	1600 GeV	2300 GeV
λ_S	0.29	0.27
λ_T	0.65	0.70
λ_{SO}	0.65	0.65
$\lambda_{SR} = \lambda_{SE}$	0.65	0.65
B_S	-2.4^2 TeV^2	-0.7^2 TeV^2
$T_{SE} = T_{SR}$	-1000 GeV	0 GeV
T_{SO}	1500 GeV	600 GeV
m_h	124.8 GeV	125.9 GeV
m_{S_R}	755.7 GeV	756.5 GeV
m_{S_I}	1125.1 GeV	751.0 GeV
m_{O_I}	886.3 GeV	886.3 GeV
m_E	382.2 GeV	386.7 GeV
$m_{\tilde{E}}$	378.6 GeV	377.2 GeV
$m_{\tilde{t}_1}$	1776.5 GeV	1597.2 GeV
$m_{\tilde{g}}$	1825.8 GeV	1916.0 GeV
ZZ	0.1	0.0
hh	0.5	1.2
WW	0.3	0.0
gg	0.7	4.4
$\Delta\rho$	9.9×10^{-5}	2.4×10^{-4}
$\sigma(S \to \gamma\gamma)$	**3.1 fb**	**4.4 fb**

- allow $T_{SE} = T_{SR}$ while having $\lambda_{SE} = \lambda_{SR}$
- allow λ_{SO} and thus larger values for T_{SO}

→ increase of production via gluons as well as decay into photons

R-symmetry violating Scenarios

“Double Peak” Scenario

Scalar and Pseudo-scalar Singlet @ 750 GeV

- without R-violation no production of pseudo-scalar Singlet

⇒ Majorana Gaugino Mass M_3 necessary

$$\Gamma(S_I \to gg) \approx \frac{9\alpha_s^2 \lambda_{SO}^2 m_{S_I}^3}{16\pi^3} \left(\frac{\cos^2\theta_{\tilde{g}}}{|M_{\tilde{g}_1}|} - \frac{\sin^2\theta_{\tilde{g}}}{|M_{\tilde{g}_2}|} \right)^2$$

$$\mathcal{L}_{m_{\tilde{g}}} = \begin{pmatrix} \lambda_3 & \chi_g \end{pmatrix} \begin{pmatrix} M_3 & M_D \\ M_D & 0 \end{pmatrix} \begin{pmatrix} \lambda_3 \\ \chi_g \end{pmatrix} + \text{h.c.}$$

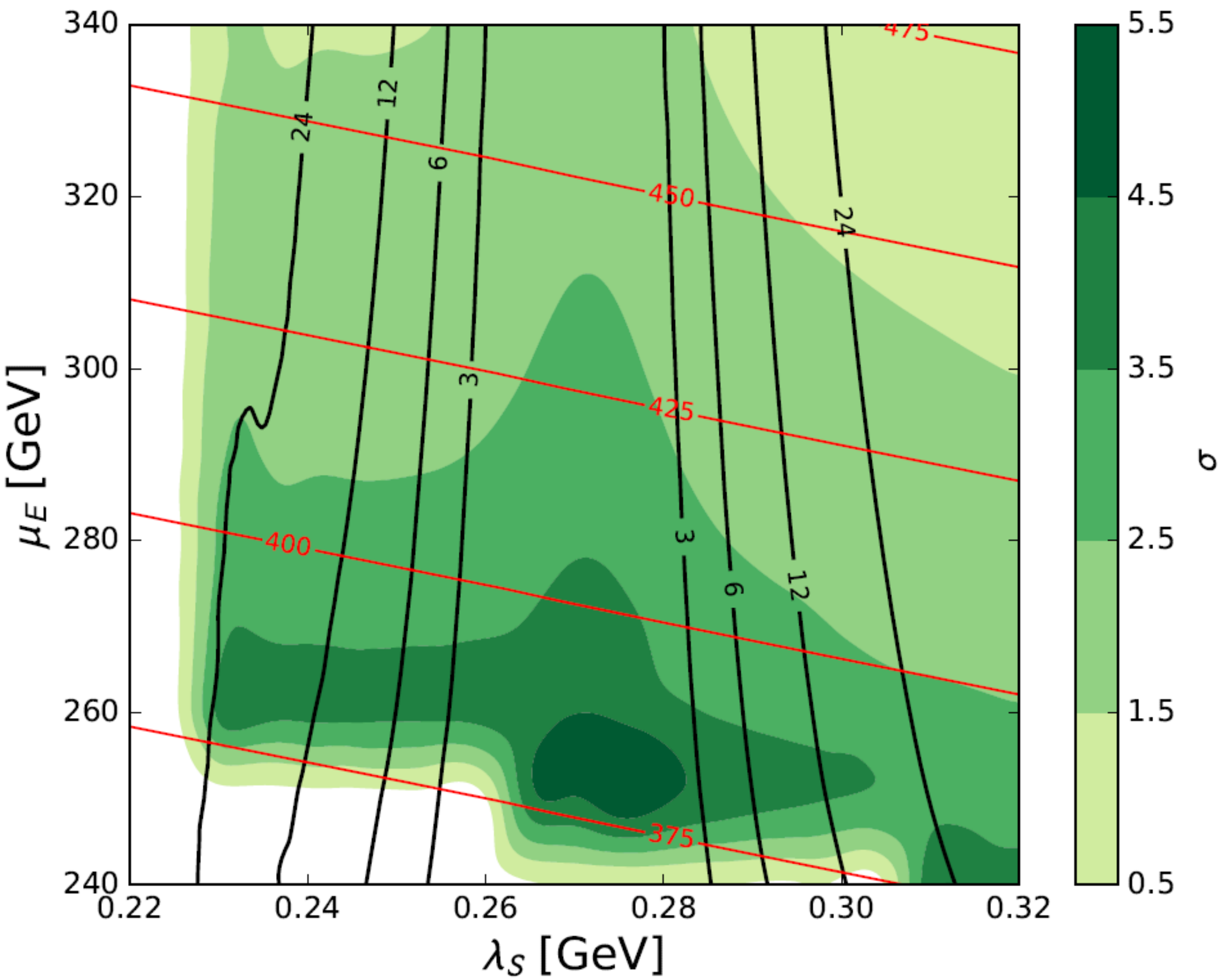
$$\begin{pmatrix} \tilde{g}_1 \\ \tilde{g}_2 \end{pmatrix} = \begin{pmatrix} \cos\theta_{\tilde{g}} & -\sin\theta_{\tilde{g}} \\ \sin\theta_{\tilde{g}} & \cos\theta_{\tilde{g}} \end{pmatrix} \begin{pmatrix} \chi_g \\ \lambda_3 \end{pmatrix}$$

in Dirac limit: $|M_{\tilde{g}_1}| = |M_{\tilde{g}_1}|$ and $\cos\theta_{\tilde{g}} = \sin\theta_{\tilde{g}} = 1/\sqrt{2}$

$\tan\beta$	2	4
μ	660 GeV	450 GeV
m_S	490 GeV	310 GeV
m_T	1250 GeV	1200 GeV
m_O	530 GeV	890 GeV
M_3	0	1400 GeV
m_{1D}	1250 GeV	490 GeV
m_{2D}	1000 GeV	1000 GeV
m_{3D}	1600 GeV	2300 GeV
λ_S	0.29	0.27
λ_T	0.65	0.70
λ_{SO}	0.65	0.65
$\lambda_{SR} = \lambda_{SE}$	0.65	0.65
B_S	-2.4^2 TeV^2	-0.7^2 TeV^2
$T_{SE} = T_{SR}$	−1000 GeV	0 GeV
T_{SO}	1500 GeV	600 GeV
m_h	124.8 GeV	125.9 GeV
m_{S_R}	755.7 GeV	756.5 GeV
m_{S_I}	1125.1 GeV	751.0 GeV
m_{O_I}	886.3 GeV	886.3 GeV
m_E	382.2 GeV	386.7 GeV
$m_{\tilde{E}}$	378.6 GeV	377.2 GeV
$m_{\tilde{t}_1}$	1776.5 GeV	1597.2 GeV
$m_{\tilde{g}}$	1825.8 GeV	1916.0 GeV
ZZ	0.1	0.0
hh	0.5	1.2
WW	0.3	0.0
gg	0.7	4.4
$\Delta\rho$	9.9×10^{-5}	2.4×10^{-4}
$\sigma(S \to \gamma\gamma)$	**3.1 fb**	**4.4 fb**

"Double Peak" Scenario

Scalar and Pseudo-scalar Singlet @ 750 GeV



$\tan\beta$	2	4
μ	660 GeV	450 GeV
m_S	490 GeV	310 GeV
m_T	1250 GeV	1200 GeV
m_O	530 GeV	890 GeV
M_3	0	1400 GeV
m_{1D}	1250 GeV	490 GeV
m_{2D}	1000 GeV	1000 GeV
m_{3D}	1600 GeV	2300 GeV
λ_S	0.29	0.27
λ_T	0.65	0.70
λ_{SO}	0.65	0.65
$\lambda_{SR} = \lambda_{SE}$	0.65	0.65
B_S	-2.4^2 TeV^2	-0.7^2 TeV^2
$T_{SE} = T_{SR}$	-1000 GeV	0 GeV
T_{SO}	1500 GeV	600 GeV
m_h	124.8 GeV	125.9 GeV
m_{S_R}	755.7 GeV	756.5 GeV
m_{S_I}	1125.1 GeV	751.0 GeV
m_{O_I}	886.3 GeV	886.3 GeV
m_E	382.2 GeV	386.7 GeV
$m_{\tilde{E}}$	378.6 GeV	377.2 GeV
$m_{\tilde{t}_1}$	1776.5 GeV	1597.2 GeV
$m_{\tilde{g}}$	1825.8 GeV	1916.0 GeV
ZZ	0.1	0.0
hh	0.5	1.2
WW	0.3	0.0
gg	0.7	4.4
$\Delta\rho$	9.9×10^{-5}	2.4×10^{-4}
$\sigma(S \to \gamma\gamma)$	**3.1 fb**	**4.4 fb**

- allows much more flexibility by enhancing TSE, increasing mass hierarchy in unification fields etc…
- reason for ATLAS claiming wide width??

Conclusions

- Minimal Dirac Gaugino Supersymmetric Standard Model is a promising model that could account for the di-photon excess

- We demonstrated in different scenarios the various possibilities of generating such a signal

  - **R-symmetric case:**

    - production via squarks or (pseudo)-scalar octets
    - Photon decay via (fake) sleptons and fake fermions

  - **R-violating case:**

    - enhancing production via largish trilinears
    - Enhancing stability by including quartics
    - Double peak scenario by introducing Majorana gaugino mass which can lead to a sizeable width

- studied thoroughly experimental constraints (LHC8 data, Higgs mixing, rho-parameter, exclusion bounds etc…)

- As well as constraints from vacuum stability and perturbativity