Models of New Physics and Flavour

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Flavourful MSSM

flavour violation in soft susy breaking terms.

$$\begin{aligned}
-\mathcal{L}_{\rm soft} &= m^2_{Q_{ii}} \tilde{Q}_i^\dagger \tilde{Q}_i + m^2_{u^c_{ii}} \tilde{u^c}^\star_i \tilde{u^c}_i + m^2_{e^c_{ii}} \tilde{e^c}^\star_i \tilde{e^c}_i + m^2_{d^c_{ii}} \tilde{d^c}^\star_i \tilde{d^c}_i + m^2_{L_{ii}} \tilde{L}_i^\dagger \tilde{L}_i \\
&+ m^2_{H_1} H_1^\dagger H_1 + m^2_{H_2} H_2^\dagger H_2 + A^u_{ij}\, \tilde{Q}_i \tilde{u^c}_j H_2 + A^d_{ij}\, \tilde{Q}_i \tilde{d^c}_j H_1 \\
&+ A^e_{ij}\, \tilde{L}_i \tilde{e^c}_j H_1 + (\Delta^l_{ij})_{\rm LL} \tilde{L}_i^\dagger \tilde{L}_j + (\Delta^l_{ij})_{\rm RR} \tilde{e^c}^\star_i \tilde{e^c}_j \\
&+ (\Delta^e_{ij})_{\rm LR} \tilde{e}_{Li}^\star \tilde{e^c_{R}}_j + \ldots
\end{aligned} \tag{1}$$

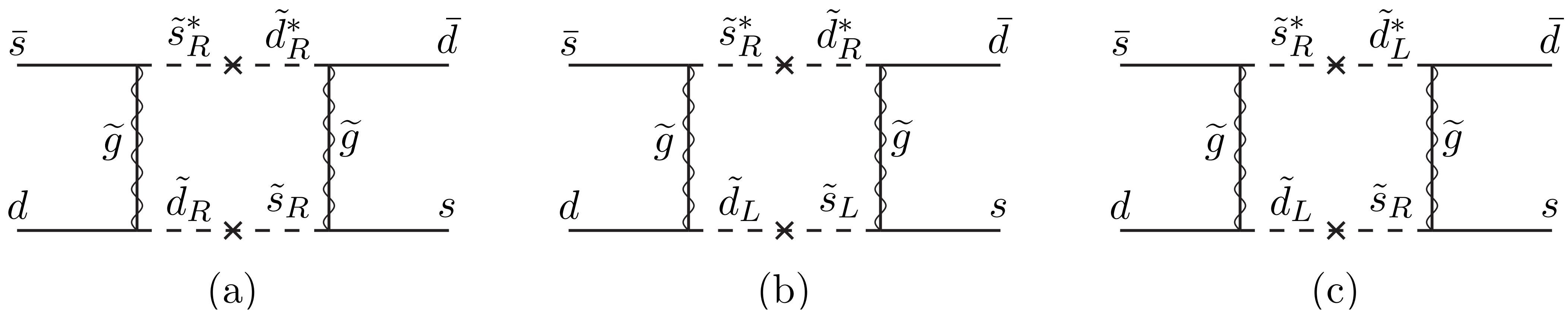
Define :

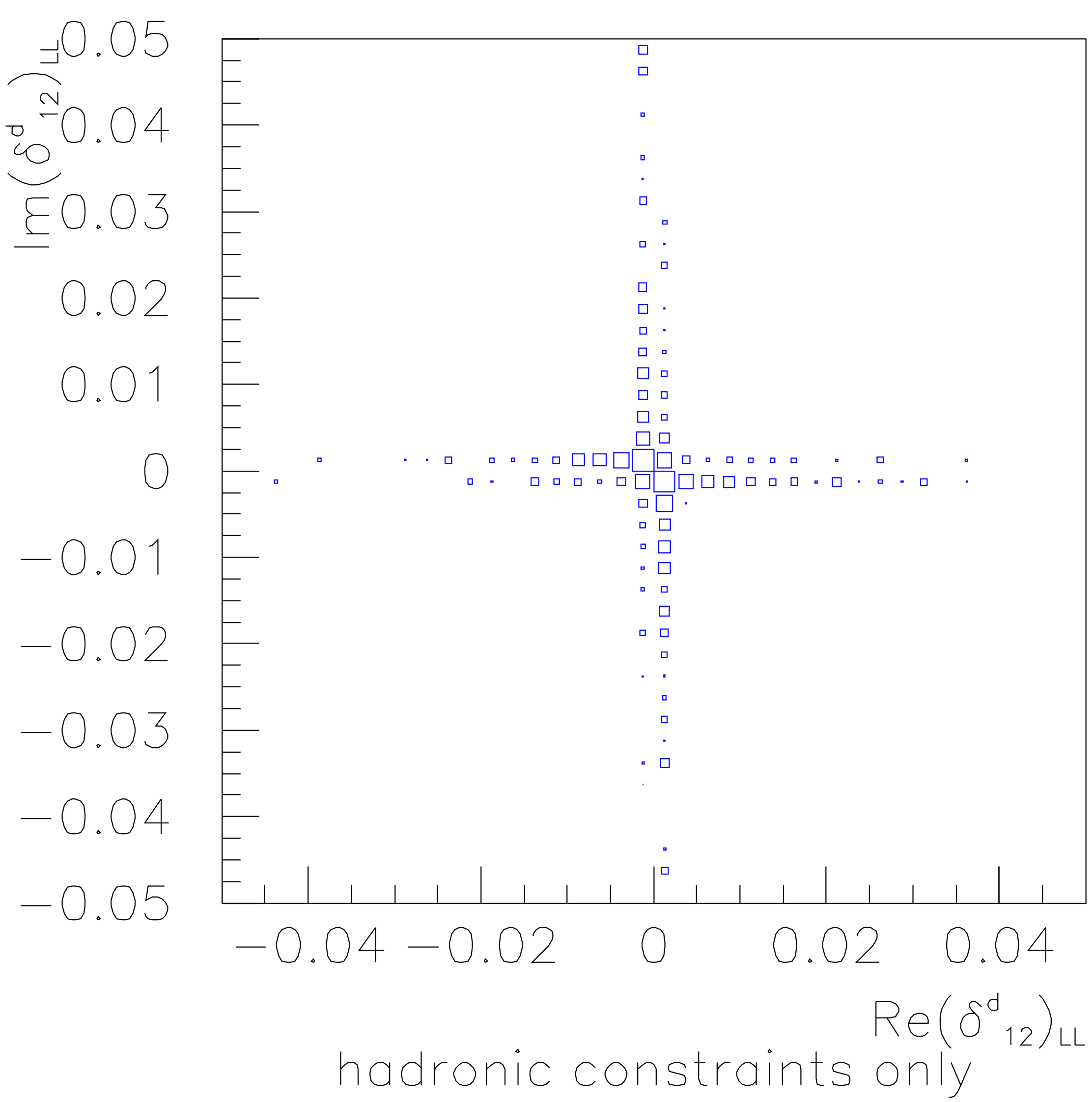
$$\delta^l_{ij} \equiv \Delta^l_{ij}/m^2_{\tilde{l}} \tag{2}$$

Ratio of flavour violating terms with flavour conserving ones.

similar parameterisation can be done for squarks

Ciuchini et. al , hep-ph/0702144



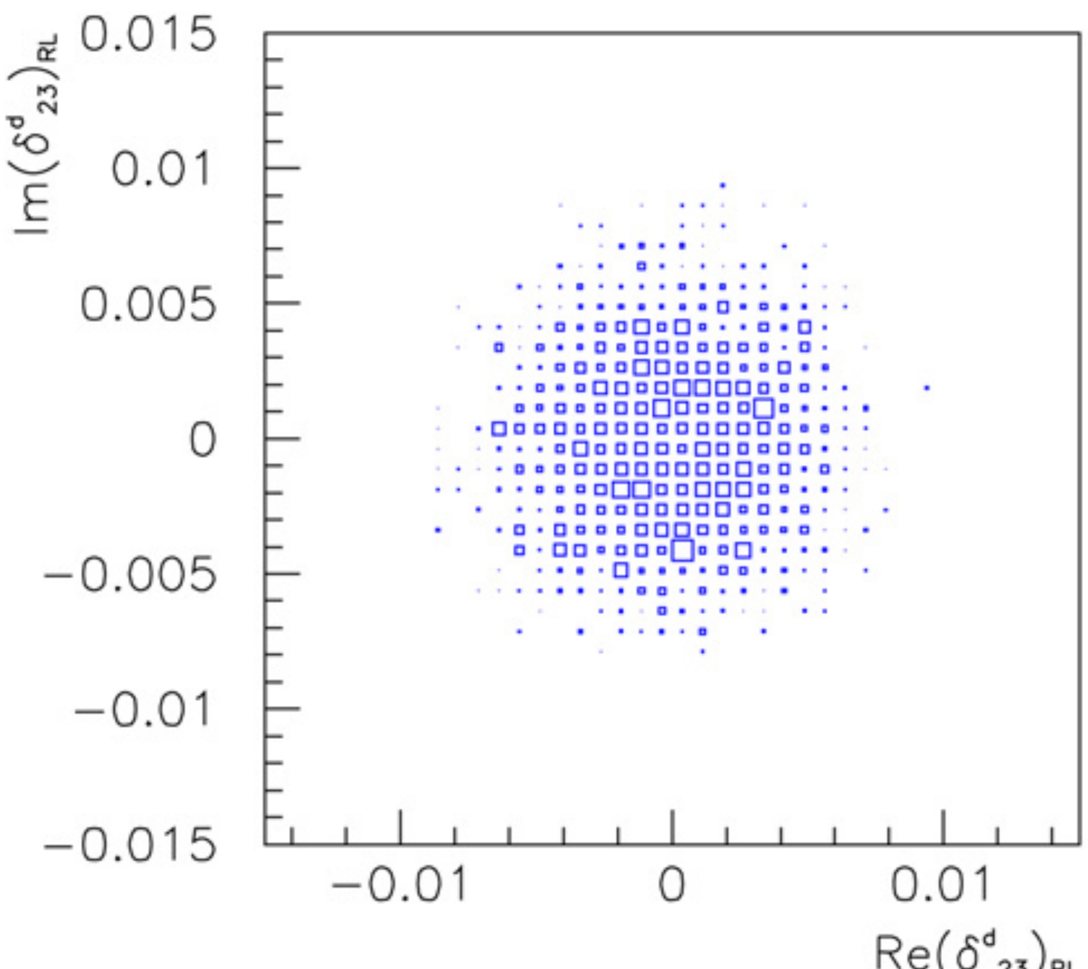


for squark masses up to 500 GeV

Ciuchini et. al , hep-ph/0702144

bounds on mass insertions in supersymmetry

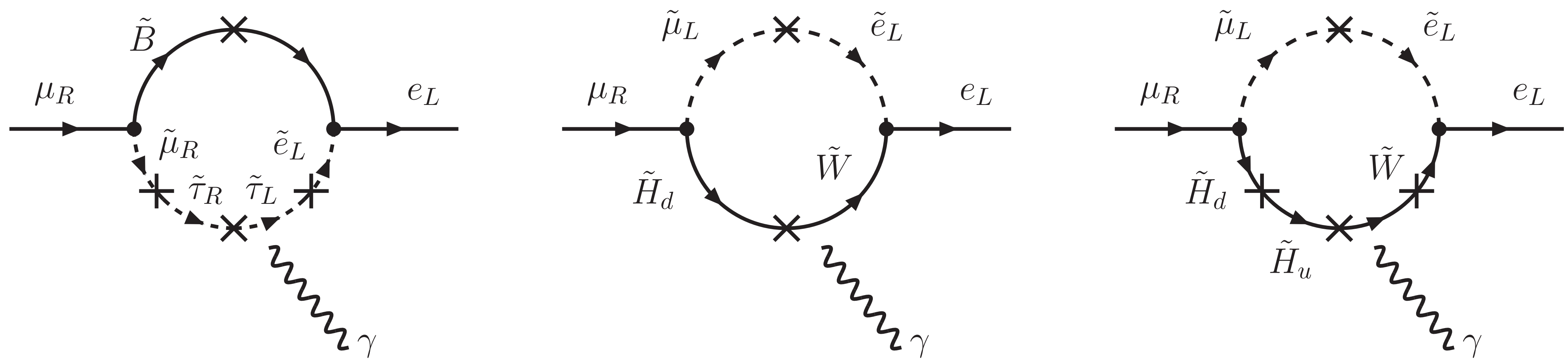
$ij\backslash AB$	LL	LR	RL	RR
12	1.4×10^{-2}	9.0×10^{-5}	9.0×10^{-5}	9.0×10^{-3}
13	9.0×10^{-2}	1.7×10^{-2}	1.7×10^{-2}	7.0×10^{-2}
23	1.6×10^{-1}	4.5×10^{-3}	6.0×10^{-3}	2.2×10^{-1}



hadronic constraints only

23 mass insertion
have less stronger
bounds

$$
\frac{M^2_{\tilde{L}}}{m^2_{\tilde{L}}} \simeq \begin{pmatrix}
1 & (\delta^l_{12})_{\rm LL} & (\delta^l_{13})_{\rm LL} & (\delta^l_{11})_{\rm LR} & (\delta^l_{12})_{\rm LR} & (\delta^l_{13})_{\rm LR} \\
(\delta^l_{12})^*_{\rm LL} & 1 & (\delta^l_{23})_{\rm LL} & (\delta^l_{21})_{\rm LR} & (\delta^l_{22})_{\rm LR} & (\delta^l_{23})_{\rm LR} \\
(\delta^l_{13})^*_{\rm LL} & (\delta^l_{23})^*_{\rm LL} & 1 & (\delta^l_{31})_{\rm LR} & (\delta^l_{32})_{\rm LR} & (\delta^l_{33})_{\rm LR} \\
(\delta^l_{11})^*_{\rm LR} & (\delta^l_{21})^*_{\rm LR} & (\delta^l_{31})^*_{\rm LR} & 1 & (\delta^l_{12})_{\rm RR} & (\delta^l_{13})_{\rm RR} \\
(\delta^l_{12})^*_{\rm LR} & (\delta^l_{22})^*_{\rm LR} & (\delta^l_{32})^*_{\rm LR} & (\delta^l_{12})^*_{\rm RR} & 1 & (\delta^l_{23})_{\rm RR} \\
(\delta^l_{13})^*_{\rm LR} & (\delta^l_{23})^*_{\rm LR} & (\delta^l_{33})^*_{\rm LR} & (\delta^l_{13})^*_{\rm RR} & (\delta^l_{23})^*_{\rm RR} & 1
\end{pmatrix}
$$



mu to e gamma diagrams

Ciuchini et. al , hep-ph/0702144

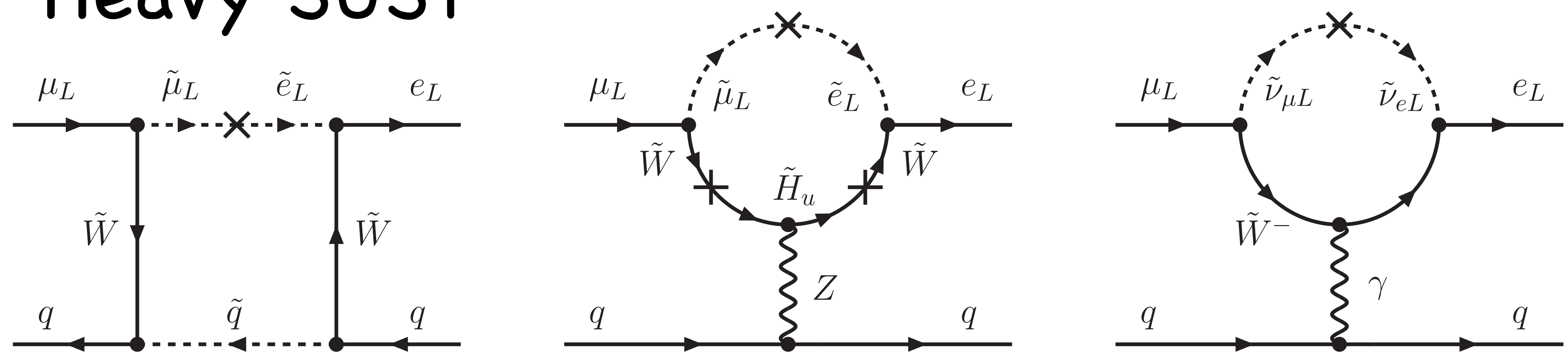
Type of δ^l_{12}	$\mu \to e\,\gamma$	$\mu \to e\,e\,e$	$\mu \to e$ conversion in Ti
LL	6×10^{-4}	2×10^{-3}	2×10^{-3}
RR	-	0.09	-
LR/RL	1×10^{-5}	3.5×10^{-5}	3.5×10^{-5}

for slepton masses close to 400 GeV and tan beta = 10

Type of δ^l_{23}	$\tau \to \mu\,\gamma$	$\tau \to \mu\,\mu\,\mu$	$\tau \to \mu\,e\,e$
LL	0.12	-	-
RR	-	-	-
LR/RL	0.03	-	0.5

for third generation, bounds are weaker

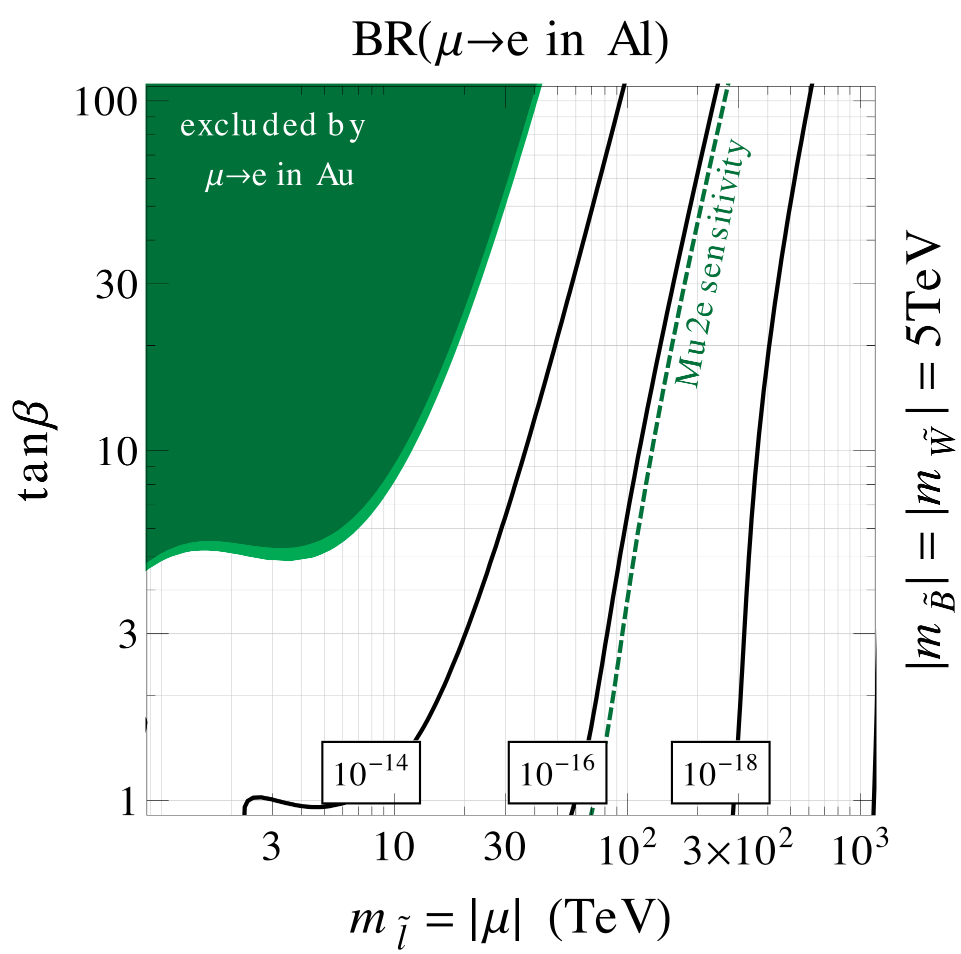
Heavy SUSY

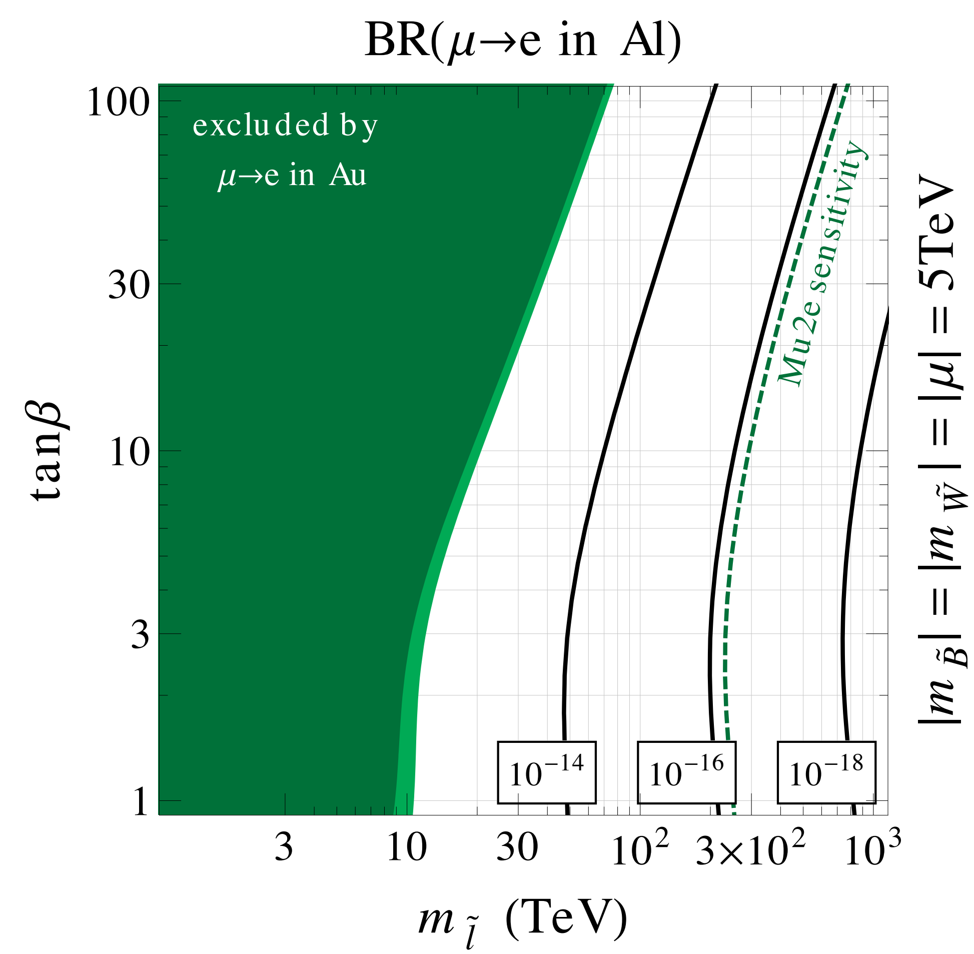


mu-e conversion diagrams

from Altmannhosfer, Harnik, Zupan, 1308.3653

The strongest limits on flavour violating entries of soft terms





Flavourful Supersymmetry has its advantages

(1) As a signature of Grand Unified theories/Seesaw mechanisms

(2) Corrections to the Higgs mass and perhaps reduce the fine tuning

Blanke et.al

(3) Change the dark matter regions (flavoured co-annihiliations etc.)

(4) Appears naturally in models reviving gauge mediated supersymmetry breaking

(5) Charge and colour breaking constraints can be comparable for flavour violating terms

Minimal Flavour Violation with SUSY

Even if all the flavour violating terms are set to zero supersymmetry can still contribute to flavour violation through CKM vertices

Misiak et.al, 1503.01789

The strongest constraint is from $B \to X_s \gamma$

which is measured very accurately and computed in SM up to four loops in QCD

$$\mathcal{B}_{s\gamma}^{\rm exp} = (3.43 \pm 0.21 \pm 0.07) \times 10^{-4},$$

$$\mathcal{B}_{s\gamma} = (3.36 \pm 0.23) \times 10^{-4}$$

In MSSM, contributions from Standard Model diagrams, Charged Higgs, Chargino and Neutralino diagrams

Large regions of various model parameter spaces are ruled out by this.

COMPRESSED SPECTRA

DEGENERATE SUSY

Models based on Scherck Schwarz SUSY breaking

Escapes limits from LHC

Indirect probes play an important role in validating these models

Setting a common scale for all soft supersymmetry breaking terms (in PMSSM) at weak scale

$$M_1 \approx M_2 \approx M_3 \equiv M_D,$$

$$m^2_{\tilde{Q}} \approx m^2_{\tilde{U}} \approx m^2_{\tilde{D}} \approx m^2_{\tilde{L}} \approx m^2_{\tilde{E}} \equiv M^2_D$$

$$|\mu|^2 = k_\mu \; M_D^2, \quad \text{and} \quad m_A^2 = k_A \; M_D^2,$$

Degenerate susy with MFV

$B \to X_s \gamma$

$$C_{7,8}^{NP} = C_{7,8}^{H} + C_{7,8}^{\tilde{H}} + C_{7,8}^{\tilde{W}} + C_{7,8}^{\tilde{g}} \;,$$

$$C_{7,8}^{H} = \left(\frac{1-\epsilon_0 t_\beta}{1+\epsilon_b t_\beta} + \frac{(\epsilon_b^{\tilde{H}})^2 t_\beta^2}{(1+\epsilon_b t_\beta)(1+\epsilon_0 t_\beta)} \right) \frac{m_t^2}{2m_{H^+}^2} h_{7,8}\left(\frac{m_t^2}{m_{H^+}^2}\right)$$

$$+ \frac{\epsilon_b^{\tilde{H}} t_\beta^3}{(1+\epsilon_b t_\beta)^2 (1+\epsilon_0 t_\beta)} \frac{m_b^2}{2m_A^2} z_{7,8},$$

$$C_7^{\tilde{H}} = -\frac{t_\beta}{1+\epsilon_b t_\beta} \frac{5}{72} \frac{A_t m_t^2}{M_D^3}, \quad C_8^{\tilde{H}} = \frac{3}{5} C_7^{\tilde{H}},$$

$$C_7^{\tilde{g}} = \frac{g_3^2}{g_2^2} \frac{\epsilon_b^{\tilde{H}} t_\beta^2}{(1+\epsilon_b t_\beta)(1+\epsilon_0 t_\beta)} \frac{2}{27} \frac{m_W^2}{M_D^2}, \quad C_8^{\tilde{g}} = \frac{15}{4} C_7^{\tilde{g}},$$

$$C_7^{\tilde{W}} = \frac{\epsilon_b^{\tilde{H}} t_\beta^2}{(1+\epsilon_b t_\beta)(1+\epsilon_0 t_\beta)} \frac{7}{24} \frac{m_W^2}{M_D^2}, \quad C_8^{\tilde{W}} = \frac{3}{7} C_7^{\tilde{W}},$$

$$\epsilon_b = \epsilon_b^{\tilde{g}} + \epsilon_b^{\tilde{W}} + \epsilon_b^{\tilde{H}} \;,$$

$$\epsilon_b^{\tilde{g}} = \frac{\alpha_s}{3\pi} \frac{\mu}{M_D},$$

$$\epsilon_b^{\tilde{W}} = -\frac{\alpha_2}{4\pi} \frac{3}{2} \mu \, M_D \, \tilde{g}(\mu^2, M_D^2)$$

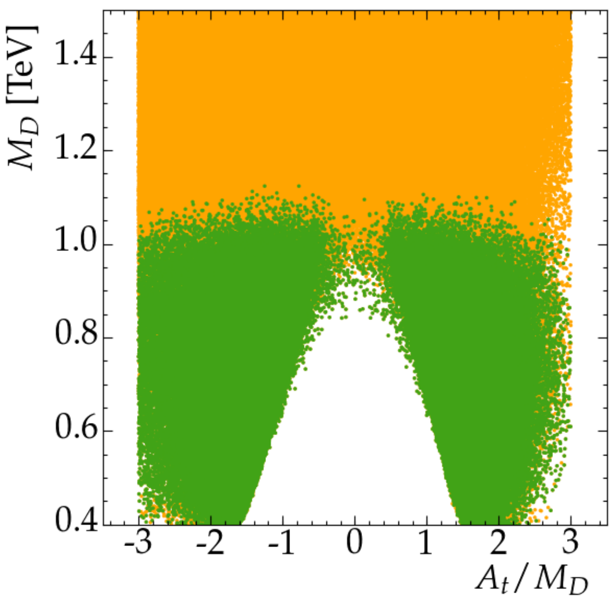
$$\epsilon_b^{\tilde{H}} = -\frac{\alpha_2}{4\pi} \frac{m_t^2}{2M_W^2} \mu \, \tilde{A}_t \, M_D \, \tilde{g}(\mu^2, M_D^2)$$

$$\epsilon_l = -\frac{\alpha_2}{4\pi} \frac{3}{2} \mu \, M_D \, \tilde{g}(\mu^2, M_D^2)$$

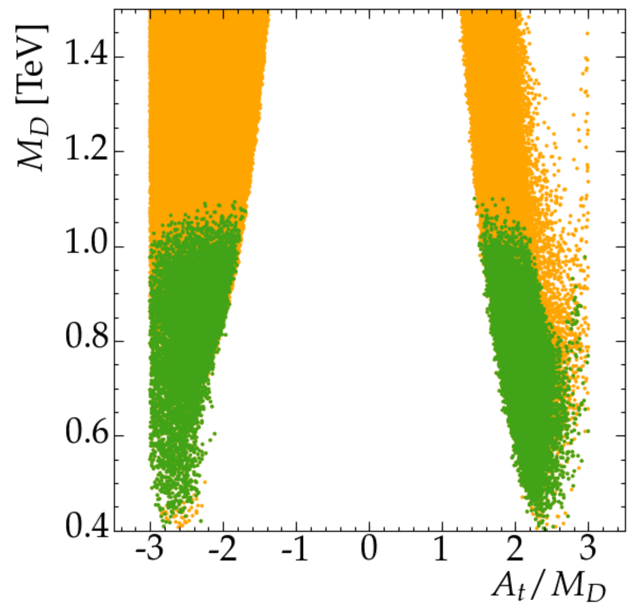
Chowdhury, Patel,
Vempati, Tata, to appear

Degenerate susy with MFV

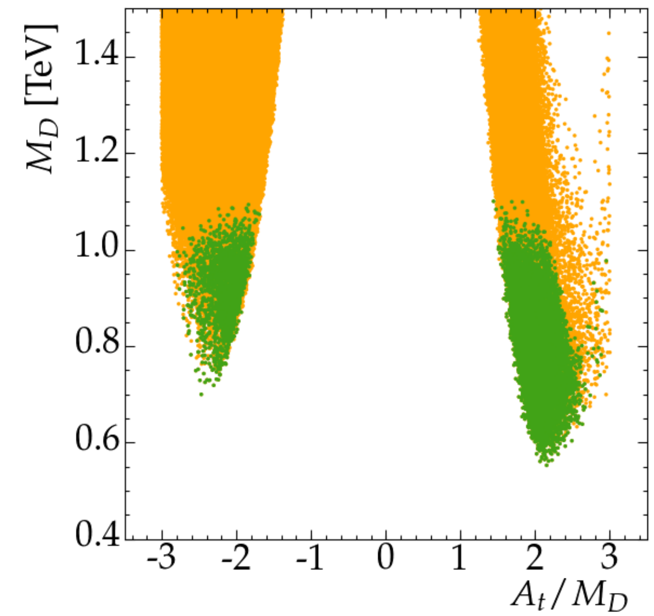
Chowdhury, Patel, Vempati, Tata, to appear



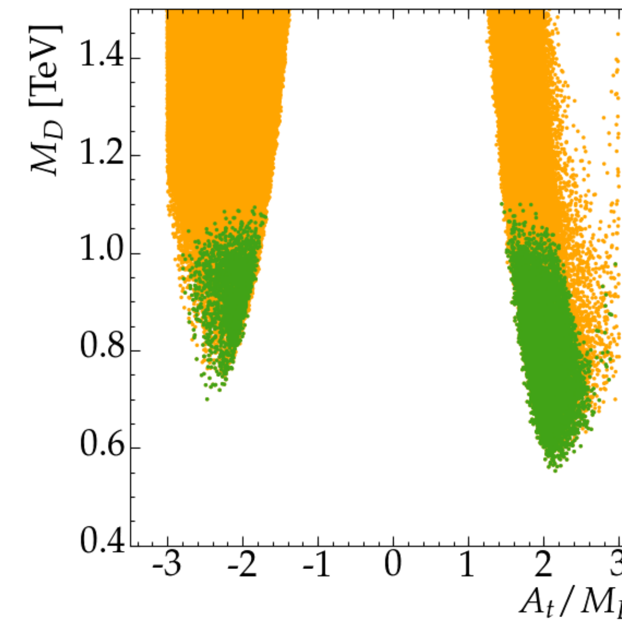
only g-2



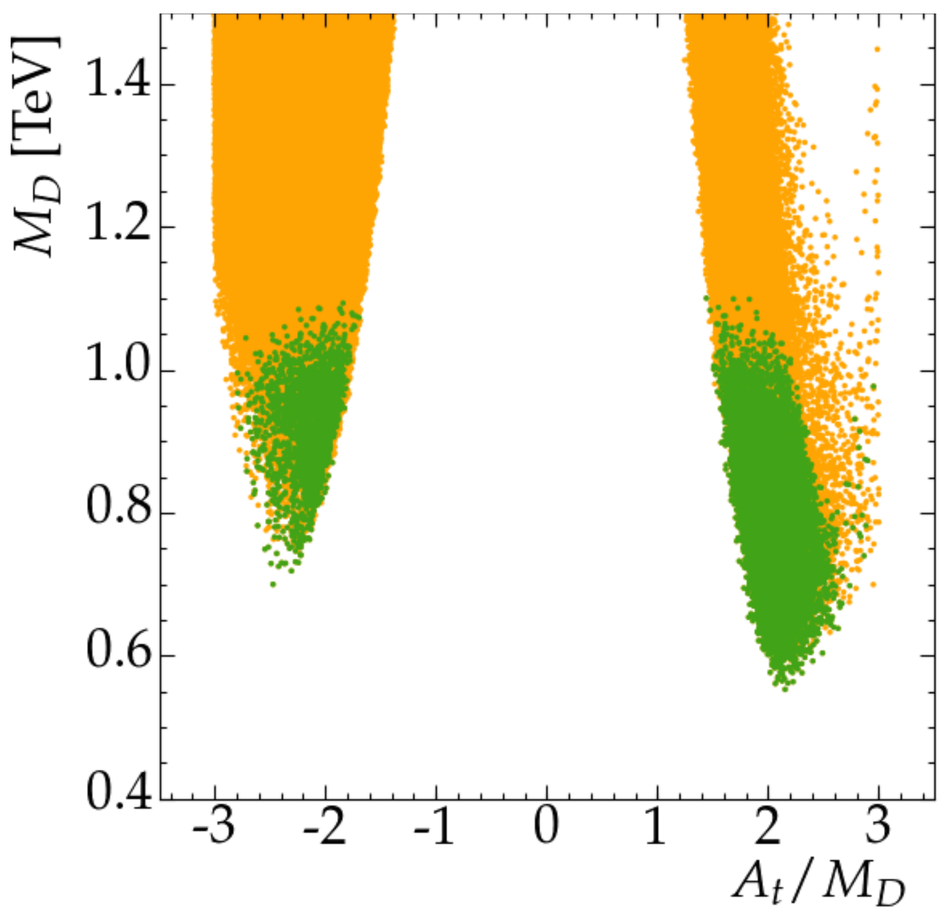
higgs

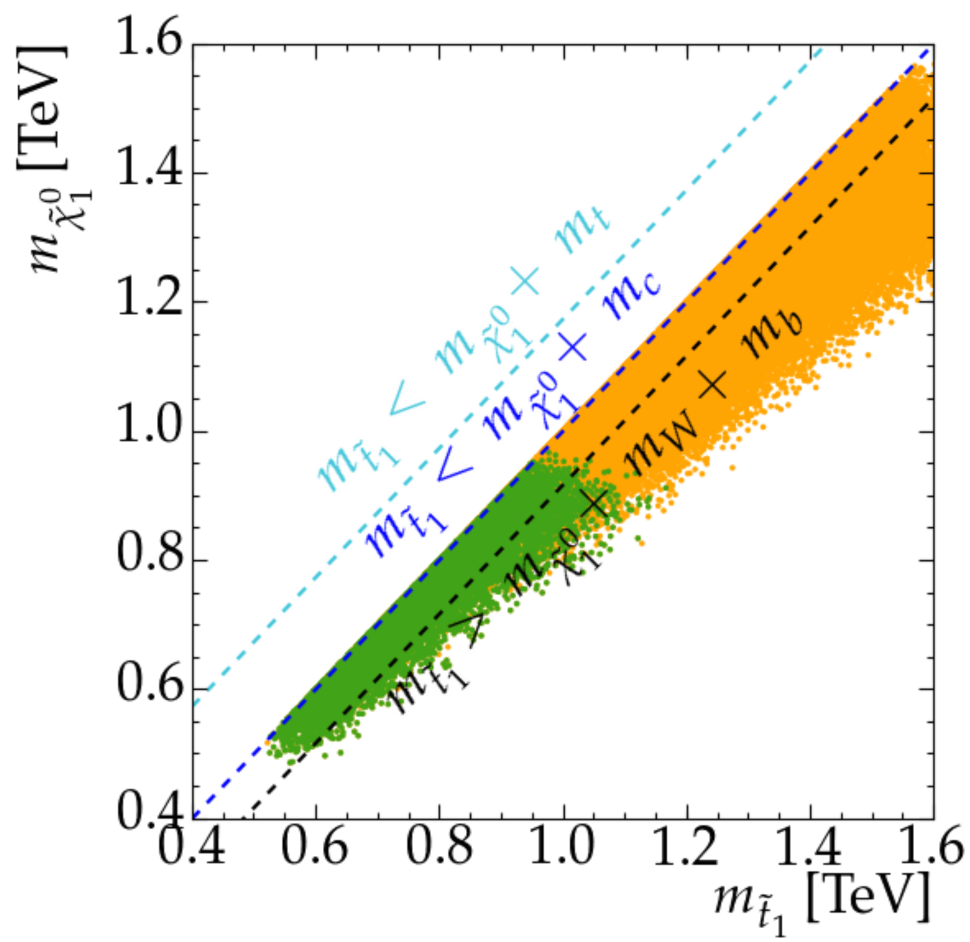


higgs + bsgamma

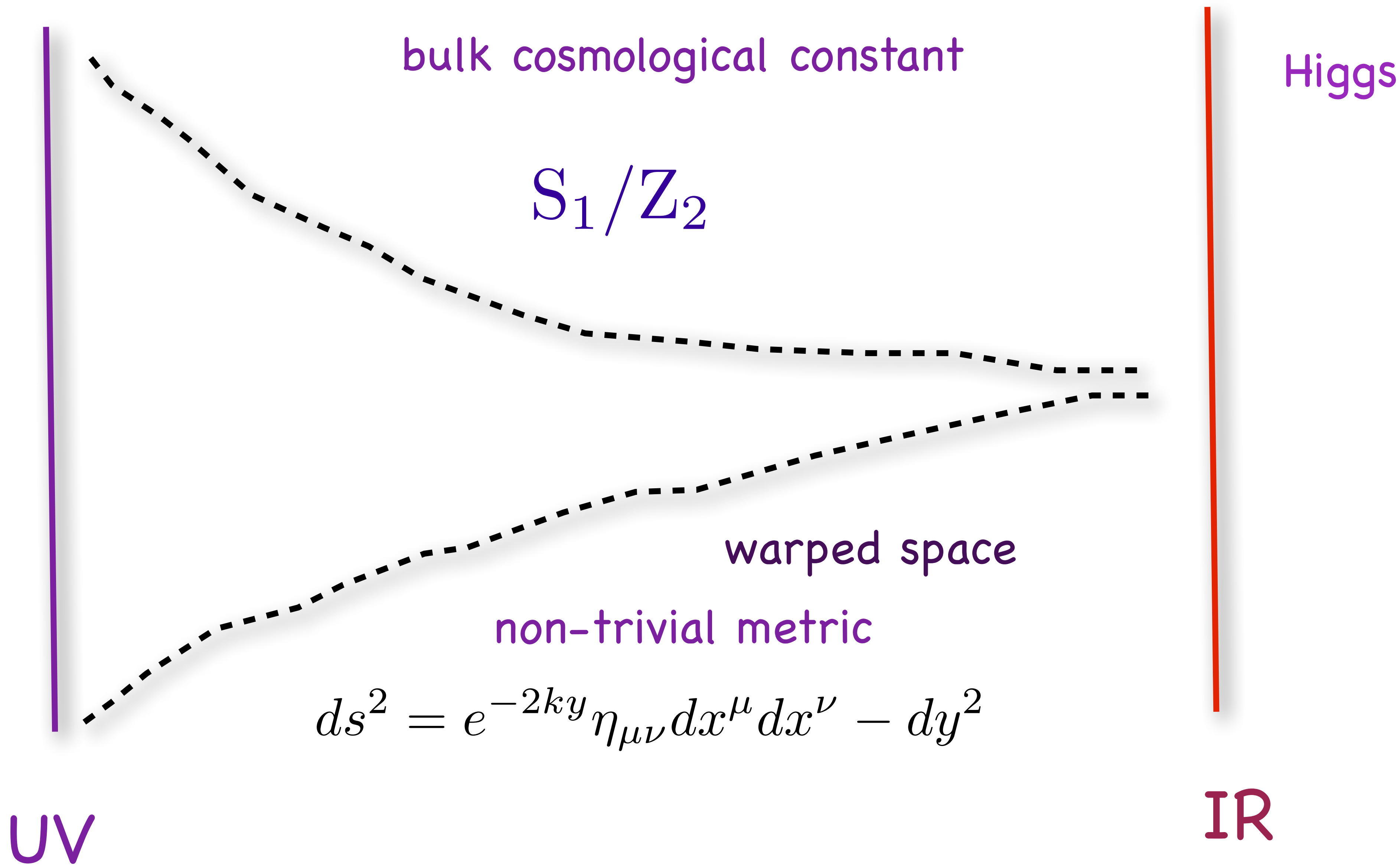


with all constraints





The Randall Sundrum Set up



Can the same set up work as theory of flavour (leptons) ?

Fermion Localisation in RS

$$\sigma(y) = 2ky$$

Natural localisation due to geometry

$$\mathcal{L}_f = e^{-3/2\sigma}\bar{\Psi}\left[i\not{\partial} - \gamma_5 e^{-\sigma}\left(\partial_y - \frac{1}{2}\sigma'\right)\right]e^{-3/2\sigma}\Psi$$

KK reduction of the fields

$$\Psi(x,y) = \frac{e^{2\sigma}}{\sqrt{\pi R}}\sum_n [\psi_L^{(n)}(x) f_L^{(n)}(y) + \psi_R^{(n)}(x) f_R^{(n)}(y)]$$

The zero modes localise close to IR brane

$$f_L^0(y) = N e^{\frac{1}{2}\sigma'(y-\pi R)}$$

Introducing bulk mass terms, wave functions can be modified.

bulk mass

$$S = \int d^4x \int dy \sqrt{-g} \left(\bar{\Psi}(i \not{D} - m)\Psi \right)$$

covariant derivative

$$f_L^0(y) = N e^{(\frac{1}{2} - c)\sigma'(y - \pi R)}$$

c is the bulk mass parameter

normalisation factor

$$\mathrm{m = ck}$$

$c > 0.5$ fields localised close to UV brane

$c < 0.5$ fields localised close to IR brane

Family Symmetries (Froggatt-Nielsen Models) and Randall Sundrum

Heavy Fermions

$$\mathcal{W} \supset Y_t Q_3 u_3 H_u + Y_1^u Q_2 F_1 H_u + Y_2^u \bar{F}_1 u_1 S + M_1 F_1 \bar{F}_1 + \cdots$$

Extra Dimension

$$S_{kin} = \int d^4x \int dy \sqrt{-g} \left(\bar{L}(i\not{D} - m_L)L + \bar{E}(i\not{D} - m_E)E + \ldots \right)$$

$$S_{\rm Yuk} = \int d^4x \int dy \sqrt{-g} \left(Y_U \bar{Q} U \tilde{H} + Y_D \bar{Q} D H + Y_E \bar{L} E H \right) \delta(y - \pi R)$$

Integrating Out

$$W \supset Y_{ij}^u \left(\frac{S}{M_{Pl}}\right)^{c_{Q_i} + c_{u_j} + c_{H_u}} Q_i H_u U_j$$

$$(\mathcal{M}_F)_{ij} = \frac{v}{\sqrt{2}} (Y_F')_{ij} e^{(1 - c_i - c_j')kR\pi} \, \xi(c_i) \, \xi(c_j')$$

$$m_F = c_F k \qquad \xi(c_i) = \sqrt{\frac{(0.5 - c_i)}{e^{(1-2c_i)\pi kR} - 1}},$$

FN models and RS

U(1) Charges

fitting both O(1) as well
U(1) charges

Bulk Masses

fitting both O(1) as well
bulk masses

Additional Conditions

Anomalies should be
cancelled, which leads to
very strong constraints

Green Schwarz Anomaly
cancellation conditions

If one doesn't consider
unification of gauge couplings,
reasonably relaxed framework

FN models and RS

Scale

Typically at Planck scale

$$< S > \sim \lambda_c M_{Pl}$$

SUSY models have D-terms

Single flavon fields strongly constrained in SUSY

Ross, Lalak etc..

Warp Factor

$$kR\pi \sim \mathcal{O}(11)$$

first KK scale around TeV

KK gauge bosons and fermions

strong constraints from Hadronic and leptonic flavour violations

Hadronic and Leptonic Flavour constraints

A combination of EWPT and flavour puts constraints on the lightest KK states of around (4-10) TeV.

Agashe, Perez, Soni,2004

Agashe, Perez, Soni,2005

Casagrande et.al ,2008

Agashe,Azatov, Zhu,2009

Bauer et.al ,2010

Blanke et. al ,2012

Malm et.al ,2015

Blanke et. al ,2008

Blanke et. al ,2009

Casagrande et. al ,2010

Grossman and Neubert,2000

Huber Shafi,2001,2002,2004

Agashe,Blechman, Petriello,2006

Moreau et.al,2006

Iyer, Vempati,2012,2013

Bulk symmetries

Fitzpatrick, Perez, Randall 2007

Cacciapaglia, Csaki, et.al 2007

Bauer et.al 2011

Little RS

Bauer et.al 2008

RS Model purely as a theory of Flavour

Iyer and Vempati
PRD 2013

no longer a solution to the hierarchy problem

M_{Planck}

$$\epsilon \sim \frac{10^{18}}{10^{16}} \sim 10^{-2}$$

small warp factor

sufficient to fit fermion masses

10^{16} GeV

SM or MSSM

M_{weak}

Very heavy KK modes $\epsilon k \sim 10^{16}$ GeV

Fermion masses at GUT scale

Mass (MeV)	Mass (GeV)	Mass MeV	Mass squared Differences eV^2
$m_u = 0.48^{+0.20}_{-0.17}$	$m_c = 0.235^{+0.035}_{-0.034}$	$m_e = 0.4696^{+0.00000004}_{-0.00000004}$	$\Delta m^2_{12} = 1.5^{+0.20}_{-0.21} \times 10^{-4}$
$m_d = 1.14^{+0.51}_{-0.48}$	$m_b = 1.0^{+0.04}_{-0.04}$	$m_\mu = 99.14^{+0.000008}_{-0.0000089}$	$\Delta m^2_{23} = 4.6^{+0.13}_{-0.13} \times 10^{-3}$
$m_s = 22^{+7}_{-6}$	$m_t = 74.0^{+4.0}_{-3.7}$	$m_\tau = 1685.58^{+0.19}_{-0.19}$	-

mixing angles(CKM)	Mixing angles (PMNS)
$\theta_{12} = 0.226^{+0.00087}_{-0.00087}$	$\theta_{12} = 0.59^{+0.02}_{-0.015}$
$\theta_{23} = 0.0415^{+0.00019}_{-0.00019}$	$\theta_{23} = 0.79^{+0.12}_{-0.12}$
$\theta_{13} = 0.0035^{+0.001}_{-0.001}$	$\theta_{13} = 0.154^{+0.016}_{-0.016}$

Results for SM

parameter	range	parameter	range	parameter	range
c_{Q_1}	[0,3.0]	c_{D_1}	[0.78,4]	c_{U_1}	[-0.97,3.98]
c_{Q_2}	[-1.95,2.36]	c_{D_2}	[0.39,3.02]	c_{U_2}	[-1.99,2.43]
c_{Q_3}	[-3,1]	c_{D_3}	[0.39,2.21]	c_{U_3}	[-4,1.0]

Dirac Case

parameter	range	parameter	range	parameter	range
c_{L_1}	[-1,2.9]	c_{E_1}	[0.39,3.62]	c_{N_1}	[5.29,8.97]
c_{L_2}	[-0.99,2.7]	c_{E_2}	[-1.0,2.63]	c_{N_2}	[5.31,8.99]
c_{L_3}	[-0.99,1.98]	c_{E_3}	[-0.99,1.93]	c_{N_3}	[5.12,8.97]

LHLH Case

parameter	range	parameter	range
c_{L_1}	[-1.5,-1.15]	c_{E_1}	[2.8,4.0]
c_{L_2}	[-1.5,-0.97]	c_{E_2}	[1.8,2.4]
c_{L_3}	[-1.5,-1.22]	c_{E_3}	[1.2,1.69]

SUSY Set up

The 5D action is given by

$$S_5 = \int d^5x \left[\int d^4\theta e^{-2ky} \left(\Phi^\dagger \Phi + \Phi^c \Phi^{c\dagger} \right) + \int d^2\theta e^{-3ky} \Phi^c \left(\partial_y + M_\Phi - \frac{3}{2}k \right) \Phi \right]$$

The 4D superpotential is given by with only zero modes

$$\mathcal{W}^{(4)} = \int dy e^{-3ky} \Big(e^{(\frac{3}{2}-c_{q_i})ky} e^{(\frac{3}{2}-c_{u_j})ky} Y^u_{ij} H_U Q_i U_j + e^{(\frac{3}{2}-c_{q_i})ky} e^{(\frac{3}{2}-c_{d_j})ky} Y^d_{ij} H_D Q_i D_j$$
$$+ \quad e^{(\frac{3}{2}-c_{L_i})ky} e^{(\frac{3}{2}-c_{E_j})ky} Y^E_{ij} H_D L_i E_j + \ldots \Big) \delta(y - \pi R)$$

$$\xi(c_i) = \sqrt{\frac{(0.5 - c_i)}{e^{(1-2c_i)\pi k R} - 1}}$$

c are the bulk mass parameters

Results for MSSM

tanbeta =10

parameter	range	parameter	range	parameter	range
c_{Q_1}	[-0.16,3.12]	c_{D_1}	[-0.5,4]	c_{U_1}	[-1.6,4.0]
c_{Q_2}	[-1.32,2.34]	c_{D_2}	[-1.9,2.5]	c_{U_2}	[-2,2.4]
c_{Q_3}	[-3,1]	c_{D_3}	[-2,1.7]	c_{U_3}	[-4,1.0]

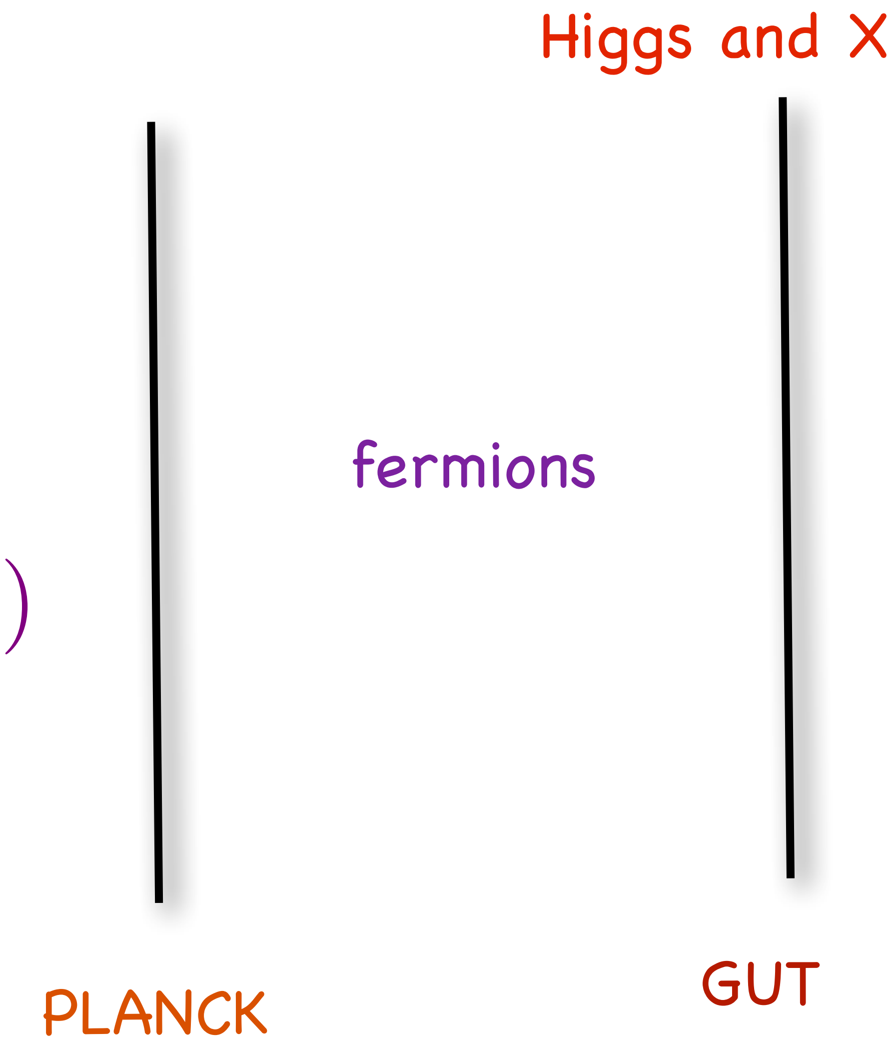
Dirac Neutrinos

parameter	range	parameter	range	parameter	range
c_{L_1}	[-1,2.6]	c_{E_1}	[-0.86,3.46]	c_{N_1}	[5.68,8.9]
c_{L_2}	[-0.99,2.21]	c_{E_2}	[-1,2.24]	c_{N_2}	[5.67,8.99]
c_{L_3}	[-1,1.54]	c_{E_3}	[-1,1.49]	c_{N_3}	[5.64,8.99]

LHLH case

parameter	range	parameter	range
c_{L_1}	[-1.5,-0.22]	c_{E_1}	[2.6,3.7]
c_{L_2}	[-1.5,0.08]	c_{E_2}	[2.0,2.57]
c_{L_3}	[-1.5,0.04]	c_{E_3}	[1.1,1.8]

SUSY Breaking



scalar masses

$$(m^2_{\tilde{f}})_{ij} = m^2_{3/2}\,\hat{\beta}_{ij}\, e^{(1-c_i-c_j)kR\pi}\xi(c_i)\xi(c_j)$$

trilinear terms

$$A^{u,d}_{ij} = m_{3/2}A'_{ij}e^{(1-c_i-c'_j)kR\pi}\xi(c_i)\xi(c'_j)$$

gaugino masses

$$m_{1/2} = f m_{3/2}$$

are fermion mass localisation dependent

SUSY breaking spurion and Higgs placed on GUT brane

Example Point

Parameter	Mass(TeV)	Parameter	Mass(TeV)	Parameter	Mass(TeV)	Parameter	Mass(Tev)	Parameter	Mass(TeV)
$\tilde{t}_1$	0.702	$\tilde{b}_1$	2.06	$\tilde{\tau}_1$	0.480	$\tilde{\nu}_\tau$	0.570	N_1	0.465
$\tilde{t}_2$	2.31	$\tilde{b}_2$	2.32	$\tilde{\tau}_2$	0.802	$\tilde{\nu}_\mu$	0.624	N_2	0.928
$\tilde{c}_R$	2.25	$\tilde{s}_R$	2.36	$\tilde{\mu}_R$	0.608	$\tilde{\nu}_e$	0.625	N_3	4.26
$\tilde{c}_L$	2.45	$\tilde{s}_L$	2.45	$\tilde{\mu}_L$	0.902	-	-	N_4	4.26
$\tilde{u}_R$	2.25	$\tilde{d}_R$	2.36	$\tilde{e}_R$	0.610	-	-	C_1	0.894
$\tilde{u}_L$	2.45	$\tilde{d}_L$	2.45	$\tilde{e}_L$	0.903	-	-	C_2	4.32
m_{A^0}	4.18	$m_H^\pm$	4.18	m_h	0.1235	m_H	3.96	-	-

(ij)	$\lvert\delta^Q_{LL}\rvert$	$\lvert\delta^L_{LL}\rvert$	$\lvert\delta^D_{LR}\rvert$	$\lvert\delta^U_{LR}\rvert$	$\lvert\delta^D_{RL}\rvert$	$\lvert\delta^U_{RL}\rvert$	$\lvert\delta^D_{RR}\rvert$	$\lvert\delta^E_{RR}\rvert$	$\lvert\delta^U_{RR}\rvert$
12	0.0003	10^{-6}	10^{-10}	10^{-8}	10^{-8}	10^{-5}	10^{-7}	10^{-7}	0.00005
13	0.01	0.007	10^{-8}	10^{-8}	10^{-5}	0.002	10^{-6}	10^{-4}	0.06
23	0.06	10^{-4}	10^{-6}	10^{-5}	10^{-5}	0.01	10^{-4}	0.0006	0.001

Dirac case $m_{3/2} = 800$ GeV; $M_{1/2} = 1200$ GeV

Bulk Higges and Unification

Dudas, Iyer, Vempati

to appear

Higgs fields localisation has now choices

M_{planck} M_{GUT}

1) Both at UV
2) Both at IR
3) H_up at UV and H_down at IR
4) H_down at UV and H_up at IR

$$\mathcal{W}^{(4)}|_{y=0} = \int dy \delta(y-0) e^{-3ky} e^{(\frac{3}{2}-c_{D_i})ky} e^{(\frac{3}{2}-c_{S_j})ky} Y'^{0}_{ij} H_{u,d} D_i S_j + \ldots$$

$$\mathcal{W}^{(4)}|_{y=\pi R} = \int dy \delta(y-\pi R) e^{-3ky} e^{(\frac{3}{2}-c_{D_i})ky} e^{(\frac{3}{2}-c_{S_j})ky} Y'^{\pi R}_{ij} H_{u,d} D_i S_j + \ldots$$

$$(\mathcal{M}_F)_{ij} = v_{u,d} \left(Y'^{\pi R}_{ij} e^{(b_{u,d}-c_i-c'_j)kr\pi} + Y'^{0} \right) \xi(c_i)\xi(c'_j)\zeta_\Phi(b_{u,d})$$

wave functions of fermion fields

lot of freedom ? ...but

wave functions of Higgs fields

Unification conditions on RS

E. Dudas et.al, JHEP 1012 (2010) 015

Unification of the gauge couplings leads to strong constraints on bulk mass parameters

$$A_3 = \sum_i (2q_i + u_i + d_i)$$

$$A_2 = \sum_i (3q_i + l_i) + h_u + h_d$$

$$A_1 = \sum_i \left(\frac{1}{3}q_i + \frac{2}{3}d_i + \frac{8}{3}u_i + 2e_i + l_i\right) + h_u + h_d$$

q_i are related to c_i

$$A_2 - A_3 = 0 \quad A_2 - \frac{3}{5}A_1 = 0$$

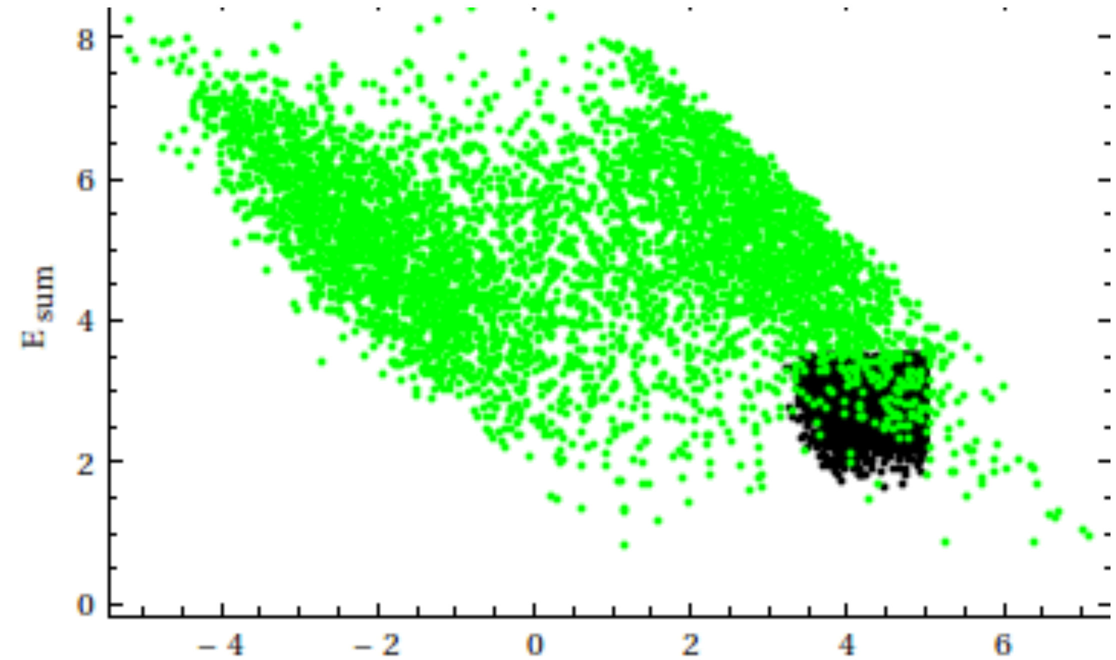
Higgs fields and spurion fields in the bulk.

Dudas, Iyer, Vempati

to appear

only the overlap region is valid

$\sum e_i$



$\sum L_i$

Hadron						Lepton			
parameter	Value	parameter	Value	parameter	Value	parameter	Value	parameter	Value
c_{Q_1}	-2.3225	c_{D_1}	3.2696	c_{U_1}	3.0093	c_{L_1}	0.5000	c_{E_1}	3.4333
c_{Q_2}	-1.0980	c_{D_2}	2.8534	c_{U_2}	1.8657	c_{L_2}	0.4990	c_{E_2}	2.2879
c_{Q_3}	-0.0422	c_{D_3}	1.7136	c_{U_3}	1.2515	c_{L_3}	-1.5000	c_{E_3}	1.0803

fit fermion masses and mixing angles well

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to appear

supersymmetry breaking contributions

universal contribution from 5D sugra

$$m^2_{tachyonic}(c_m, c_s) = -2m^2_{3/2}\left(1+2\alpha_{ms}\right) \quad \text{where}$$

$$1+2\alpha_{ms} = \frac{(1-2c_m)(2-2c_s)}{2(4-2c_m-2c_s)}\left(\frac{(1-\epsilon^{3-2c_m})(1-\epsilon^{3-2c_s})}{\epsilon^2(1-\epsilon^{1-2c_m})(1-\epsilon^{1-2c_s})}-1\right)$$

non tachyonic sources

$$m^2_{ij} = m^2_{3/2} r^2 \hat{m}_{ij}\left(\xi_{UV}(c_i)\xi_{UV}(c_j)\xi^2_{UV}(c_S) + \frac{1}{\epsilon^2}\xi_{IR}(c_i)\xi_{IR}(c_j)\xi^2_{IR}(c_S)\right)$$

$$M_{1,2,3} = m_{3/2} r^{3/2} \hat{M}_{1,2,3}\left(\xi_{UV} + \xi_{UV}\epsilon^{c_S-1.5}\right)$$

$$\mathcal{A}_{ijh} = m_{3/2} r^2 \hat{A}_{ij}\left(\xi_{UV}(c_i)\xi_{UV}(c_j)\xi_{UV}(c_h)\xi_{UV}(c_S) + \frac{1}{\epsilon}\xi_{IR}(c_i)\xi_{IR}(c_j)\xi_{IR}(c_h)\xi_{IR}(c_S)\right)$$

$$r = \frac{k}{M_5}$$

c_S SUSY breaking Bulk parameter

all flavour dependent

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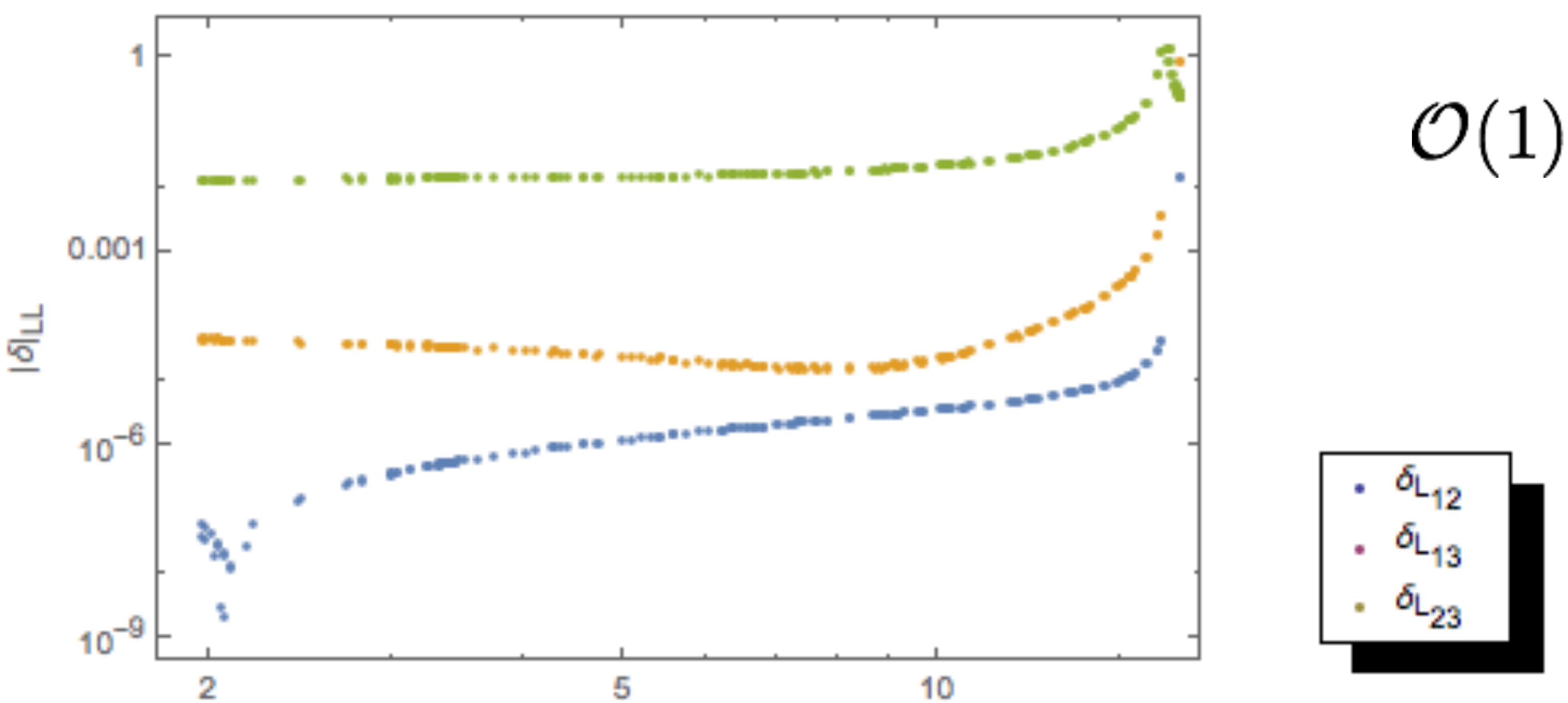
to appear

running to the weak scale in flavourful supersymmetry at high scale



$\mathcal{O}(1)$ flavour violation at high scale becomes small at weak scale

can lead to $\tau \to \mu + \gamma$ in $10^{-9} - 10^{-10}$ in BR.

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to appear

GUT scale flavour violation

(i,j)	$\|\delta^Q_{LL}\|$	$\|\delta^L_{LL}\|$	$\|\delta^D_{LR}\|$	$\|\delta^U_{LR}\|$	$\|\delta^D_{RL}\|$	$\|\delta^U_{RL}\|$	$\|\delta^D_{RR}\|$	$\|\delta^U_{RR}\|$	$\|\delta^E_{RR}\|$
12	.41	0.0005	10^{-9}	10^{-8}	10^{-8}	10^{-4}	0.01	0.02	0.07
13	.75	0.0005	10^{-9}	10^{-8}	10^{-5}	10^{-4}	0.03	0.006	0.009
23	.29	0.27	10^{-6}	10^{-3}	10^{-4}	0.001	0.13	0.18	0.20

weak scale flavour violation

(i,j)	$\|\delta^Q_{LL}\|$	$\|\delta^L_{LL}\|$	$\|\delta^D_{LR}\|$	$\|\delta^U_{LR}\|$	$\|\delta^D_{RL}\|$	$\|\delta^U_{RL}\|$	$\|\delta^D_{RR}\|$	$\|\delta^U_{RR}\|$	$\|\delta^E_{RR}\|$
12	10^{-5}	10^{-7}	10^{-14}	10^{-15}	10^{-13}	10^{-9}	10^{-9}	10^{-6}	10^{-5}
13	0.0004	10^{-5}	10^{-13}	10^{-10}	10^{-9}	10^{-6}	10^{-6}	10^{-5}	10^{-4}
23	0.004	10^{-2}	10^{-11}	10^{-7}	10^{-9}	10^{-5}	10^{-5}	0.08	10^{-2}

$m_{\tilde{g}} = 3.56$ TeV, $\mu = 2.36$TeV, $tan\beta = 25$

Parameter	Mass(TeV)	Parameter	Mass(TeV)	Parameter	Mass(TeV)	Parameter	Mass(Tev)	Parameter	Mass(TeV)
$\tilde{t}_1$	2.24	$\tilde{b}_1$	2.94	$\tilde{\tau}_1$	0.35	$\tilde{\nu}_\tau$	0.56	N_1	0.171
$\tilde{t}_2$	3.01	$\tilde{b}_2$	3.01	$\tilde{\tau}_2$	0.65	$\tilde{\nu}_\mu$	0.82	N_2	1.37
$\tilde{c}_R$	2.90	$\tilde{s}_R$	3.12	$\tilde{\mu}_R$	0.82	$\tilde{\nu}_e$	0.89	N_3	2.37
$\tilde{c}_L$	3.24	$\tilde{s}_L$	3.24	$\tilde{\mu}_L$	0.95	-	-	N_4	2.37
$\tilde{u}_R$	2.90	$\tilde{d}_R$	3.12	$\tilde{e}_R$	0.82	-	-	C_1	1.33
$\tilde{u}_L$	3.24	$\tilde{d}_L$	3.24	$\tilde{e}_L$	0.95	-	-	C_2	2.36
m_{A^0}	4.79	$m_H^\pm$	4.79	m_h	0.119	m_H	4.83	-	-

Outlook

Flavour puts strong constraints on New Physics models.

At the same time, it is also very useful in “solving” various problems in new Physics models.

Flavour violation remains the strongest “indicator” of new physics probing scales sometimes higher than that of LHC