Models of New Physics and Flavour

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Flavourful MSSM

flavour violation in soft susy breaking terms.

\[-L_{\text{soft}} = m^2_{Q_i} \tilde{Q}_i \tilde{Q}_i + m^2_{u_{ii}} \tilde{u}_{ii}^c \tilde{u}_i + m^2_{e_{ii}} \tilde{e}_i \tilde{e}_i + m^2_{d_{ii}} \tilde{d}_i \tilde{d}_i + m^2_{L_{ii}} \tilde{L}_i \tilde{L}_i + m^2_{H_1} H_1^\dagger H_1 + m^2_{H_2} H_2^\dagger H_2 + A^u_{ij} \tilde{Q}_i \tilde{u}_j H_2 + A^d_{ij} \tilde{Q}_i \tilde{d}_j H_1 + A^e_{ij} \tilde{L}_i \tilde{e}_j H_1 + (\Delta^l_{ij})_{LL} \tilde{L}_i \tilde{L}_j + (\Delta^l_{ij})_{RR} \tilde{e}_i \tilde{e}_j + (\Delta^e_{ij})_{LR} \tilde{e}_L \tilde{e}_R + \ldots \]  

(1)

Define:

\[
\delta^l_{ij} \equiv \Delta^l_{ij}/m^2_i
\]  

(2)

Ratio of flavour violating terms with flavour conserving ones.

similar parameterisation can be done for squarks
Figure 6.7: Some of the diagrams that contribute to experimental value 3. For example, suppose that there is a non-zero right-handed d winos are exchanged, which can be important depending on the and associated CP-violating complex phases, that one can to gets contributions from the diagrams in Figure 6.7, among ot constraints on the o severely restrict the amounts of

More generally, limits on

fig. 6.7b. The numerical constraint is \[93\]:

corresponding to the down-type quark mass eigenstates. An e

for squark masses up to 500 GeV

hadronic constraints only
bounds on mass insertions in supersymmetry

<table>
<thead>
<tr>
<th>$ij \backslash AB$</th>
<th>LL</th>
<th>LR</th>
<th>RL</th>
<th>RR</th>
</tr>
</thead>
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<td>$1.4 \times 10^{-2}$</td>
<td>$9.0 \times 10^{-5}$</td>
<td>$9.0 \times 10^{-5}$</td>
<td>$9.0 \times 10^{-3}$</td>
</tr>
<tr>
<td>13</td>
<td>$9.0 \times 10^{-2}$</td>
<td>$1.7 \times 10^{-2}$</td>
<td>$1.7 \times 10^{-2}$</td>
<td>$7.0 \times 10^{-2}$</td>
</tr>
<tr>
<td>23</td>
<td>$1.6 \times 10^{-1}$</td>
<td>$4.5 \times 10^{-3}$</td>
<td>$6.0 \times 10^{-3}$</td>
<td>$2.2 \times 10^{-1}$</td>
</tr>
</tbody>
</table>

23 mass insertion have less stronger bounds
Compared to the bino contributions (16), (17) they arise at linear order in mass insertion, scale SUSY).

loop size, compared to the case where all mass parameters are at the same scale (as in TeV slepton mass, roughly by a loop factor. E

proportional to the bino mass linearly with

in Fig. 8 (left-most diagram) and gives

over the contributions linear in the mass insertions. The relevant Feynman diagram is shown

The dominant bino contribution arises at second order in mass insertions,

important in TeV scale SUSY with large tan

from bino and wino loops [77–79]. Higgs mediated contributions to

Middle and right: wino-higgsino contributions.

FIG. 8: Example contributions to the

µ to e gamma diagrams
TABLE V: Bounds on leptonic transitions.

<table>
<thead>
<tr>
<th>Type of $\delta_{12}$</th>
<th>$\mu \to e \gamma$</th>
<th>$\mu \to e e e$</th>
<th>$\mu \to e$ conversion in Ti</th>
</tr>
</thead>
<tbody>
<tr>
<td>LL</td>
<td>$6 \times 10^{-4}$</td>
<td>$2 \times 10^{-3}$</td>
<td>$2 \times 10^{-3}$</td>
</tr>
<tr>
<td>RR</td>
<td>-</td>
<td>0.09</td>
<td>-</td>
</tr>
<tr>
<td>LR/RL</td>
<td>$1 \times 10^{-5}$</td>
<td>$3.5 \times 10^{-5}$</td>
<td>$3.5 \times 10^{-5}$</td>
</tr>
</tbody>
</table>

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

for third generation, bounds are weaker
The general form of the charges. Note that the photon penguin is enhanced by a large logarithm, \( \log(\cdot) \).

The strongest limits on flavour violating entries of soft terms from Altmannhosfer, Harnik, Zupan, 1308.3653

**Heavy SUSY**

![Muon-e conversion diagrams]

\[
\begin{align*}
    \mu_L & \quad \tilde{\mu}_L & \quad \tilde{e}_L & \quad e_L \\
    \tilde{W}^- & \quad q & \quad \tilde{q} & \quad q \\
    \mu_L & \quad \tilde{\mu}_L & \quad \tilde{e}_L & \quad e_L \\
    \tilde{W}^- & \quad Z & \quad q & \quad q \\
    \mu_L & \quad \tilde{\nu}_\mu & \quad \tilde{\nu}_e & \quad e_L \\
    \tilde{W}^- & \quad \gamma & \quad q & \quad q
\end{align*}
\]
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-annihilations 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.

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

\[
B_{s\gamma}^{\text{exp}} = (3.43 \pm 0.21 \pm 0.07) \times 10^{-4},
\]

\[
B_{s\gamma} = (3.36 \pm 0.23) \times 10^{-4}
\]

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.
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:

\[ M_1 \approx M_2 \approx M_3 \equiv M_D, \]

\[ m_\tilde{Q}^2 \approx m_\tilde{U}^2 \approx m_\tilde{D}^2 \approx m_\tilde{L}^2 \approx m_\tilde{E}^2 \equiv M_D^2 \]

\[ |\mu|^2 = k_\mu \ M_D^2, \quad \text{and} \quad m_A^2 = k_A \ M_D^2, \]
Degenerate susy with MFV

\[ B \rightarrow X_s \gamma \]

\[ C_{7,8}^{NP} = C_{7,8}^H + C_{7,8}^{\tilde{t}} + C_{7,8}^{\tilde{W}} + C_{7,8}^{\tilde{g}} , \]

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

\[ + \frac{\epsilon_b \tilde{t}_\beta^3}{(1 + \epsilon_b t_\beta)^2(1 + \epsilon_0 t_\beta)} \frac{m_b^2}{2 m_A^2} z_{7,8} , \]

\[ C_{7}^{\tilde{t}} = -\frac{t_\beta}{1 + \epsilon_b t_\beta} \frac{5}{72} \frac{A_t m_t^2}{M_D^3} , \quad C_{8}^{\tilde{g}} = \frac{3}{5} C_{7}^{\tilde{t}} , \]

\[ C_{7}^{\tilde{W}} = \frac{g_3^2}{g_2^2} \frac{(1 + \epsilon_b t_\beta)(1 + \epsilon_0 t_\beta)}{27} \frac{2 m_W^2}{M_D^2} , \quad C_{8}^{\tilde{W}} = \frac{3}{7} C_{7}^{\tilde{W}} , \]

\[ \frac{g_3^2}{g_2^2} \frac{\epsilon_b \tilde{t}_\beta^2}{(1 + \epsilon_b t_\beta)(1 + \epsilon_0 t_\beta)} \frac{2 m_W^2}{24 M_D^2} , \quad C_{8}^{\tilde{g}} = \frac{15}{4} C_{7}^{\tilde{g}} , \]

\[ \frac{\epsilon_b \tilde{t}_\beta^2}{(1 + \epsilon_b t_\beta)(1 + \epsilon_0 t_\beta)} \frac{7 m_W^2}{24 M_D^2} , \quad C_{8}^{\tilde{g}} = \frac{3}{7} C_{7}^{\tilde{W}} , \]

\[ \epsilon_b = \frac{\epsilon_b + \epsilon_b^{W} + \epsilon_b^{\tilde{t}}}{\alpha_s}{\frac{\mu}{3\pi}} M_D , \]

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

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

\[ \epsilon_t = -\frac{\alpha_2}{4\pi} \frac{3}{2} \mu M_D \tilde{g}(\mu^2, M_D^2) . \]
Degenerate susy with MFV

only g-2

higgs

higgs + bsgamma

with all constraints

Chowdhury, Patel, Vempati, Tata, to appear
The Randall Sundrum Set up

bulk cosmological constant

$S_1/Z_2$

warped space

non-trivial metric

$$ds^2 = e^{-2ky} \eta_{\mu\nu} dx^\mu dx^\nu - dy^2$$

Higgs

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

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

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.

\[ S = \int d^4x \int dy \sqrt{-g} (\bar{\Psi} (i \not{\partial} - m) \Psi) \]

- **bulk mass**
- **covariant derivative**
- **normalisation factor**
- **c is the bulk mass parameter**
- \( m = ck \)

\[ f^0_L(y) = Ne^{(\frac{1}{2} - c)\sigma'(y - \pi R)} \]

- \( c > 0.5 \) 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

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

Extra Dimension

\[
S_{\text{kin}} = \int d^4 x \int dy \sqrt{-g} \left( \bar{L}(i/P - m_L)L + \bar{E}(i/P - m_E)E + \cdots \right)
\]

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

Integrating Out

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

\[
(M_F)_{ij} = \frac{v}{\sqrt{2}} (Y'_F)_{ij} e^{(1-c_i-c_j') k R \pi} \xi(c_i) \xi(c_j')
\]

\[
m_F = c_F k \quad \xi(c_i) = \sqrt{\frac{(0.5 - c_i)}{e^{(1-2c_i) \pi k R} - 1}},
\]
FN models and RS

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

Bulk Masses
fitting both O(1) as well as 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

\[ \langle S \rangle \sim \lambda_c M_{Pl} \]

SUSY models have D-terms

Single flavon fields strongly constrained in SUSY

Ross, Lalak etc..

Warp Factor

\[ k R \pi \sim O(11) \]

first KK scale around TeV

KK gauge bosons and fermions

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

**Bulk symmetries**
- Fitzpatrick, Perez, Randall 2007
- Cacciapaglia, Csaki, et.al 2007
- Bauer et.al 2011

**Little RS**
- Bauer et.al 2008

**References**
- Agashe, Perez, Soni, 2004
- Agashe, Perez, Soni, 2005
- Casagrande et.al, 2008
- Agashe, Azatov, Zhu, 2009
- Blanke et. al, 2008
- Blanke et. al, 2009
- Casagrande et. al, 2010
- Grossman and Neubert, 2000
- Agashe, Blechman, Petriello, 2006
- Moreau et.al, 2006
- Bauer et.al, 2010
- Blanke et. al, 2012
- Malm et.al, 2015
RS Model purely as a theory of Flavour

no longer a solution to the hierarchy problem

\[ M_{\text{Planck}} \quad \text{______________} \]

\[ 10^{16} \text{ GeV} \quad \text{______________} \]

\[ \epsilon \sim \frac{10^{18}}{10^{16}} \sim 10^{-2} \quad \text{small warp factor} \]

sufficient to fit fermion masses

SM or MSSM

\[ M_{\text{weak}} \quad \text{______________} \]

Very heavy KK modes \[ \epsilon k \sim 10^{16} \text{ GeV} \]
Fermion masses at GUT scale

<table>
<thead>
<tr>
<th>Mass (MeV)</th>
<th>Mass (GeV)</th>
<th>Mass MeV</th>
<th>Mass squared Differences (eV^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(m_u = 0.48^{+0.20}_{-0.17})</td>
<td>(m_c = 0.235^{+0.035}_{-0.034})</td>
<td>(m_e = 0.4696^{+0.0000004}_{-0.0000004})</td>
<td>(\Delta m_{12}^2 = 1.5^{+0.20}_{-0.21} \times 10^{-4})</td>
</tr>
<tr>
<td>(m_d = 1.14^{+0.51}_{-0.48})</td>
<td>(m_b = 1.0^{+0.04}_{-0.04})</td>
<td>(m_\mu = 99.14^{+0.00008}_{-0.000089})</td>
<td>(\Delta m_{23}^2 = 4.6^{+0.13}_{-0.13} \times 10^{-3})</td>
</tr>
<tr>
<td>(m_s = 22^{+7}_{-6})</td>
<td>(m_t = 74.0^{+4.0}_{-3.7})</td>
<td>(m_\tau = 1685.58^{+0.19}_{-0.19})</td>
<td>-</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mixing angles (CKM)</th>
<th>Mixing angles (PMNS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\theta_{12} = 0.226^{+0.00087}_{-0.00087})</td>
<td>(\theta_{12} = 0.59^{+0.02}_{-0.015})</td>
</tr>
<tr>
<td>(\theta_{23} = 0.0415^{+0.00019}_{-0.00019})</td>
<td>(\theta_{23} = 0.79^{+0.12}_{-0.12})</td>
</tr>
<tr>
<td>(\theta_{13} = 0.0035^{+0.001}_{-0.001})</td>
<td>(\theta_{13} = 0.154^{+0.016}_{-0.016})</td>
</tr>
</tbody>
</table>
### Results for SM

#### Dirac Case

<table>
<thead>
<tr>
<th>parameter</th>
<th>range</th>
<th>parameter</th>
<th>range</th>
<th>parameter</th>
<th>range</th>
</tr>
</thead>
<tbody>
<tr>
<td>$c_{Q_1}$</td>
<td>[0,3.0]</td>
<td>$c_{D_1}$</td>
<td>[0.78,4]</td>
<td>$c_{U_1}$</td>
<td>[-0.97,3.98]</td>
</tr>
<tr>
<td>$c_{Q_2}$</td>
<td>[-1.95,2.36]</td>
<td>$c_{D_2}$</td>
<td>[0.39,3.02]</td>
<td>$c_{U_2}$</td>
<td>[-1.99,2.43]</td>
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<tr>
<td>$c_{Q_3}$</td>
<td>[-3,1]</td>
<td>$c_{D_3}$</td>
<td>[0.39,2.21]</td>
<td>$c_{U_3}$</td>
<td>[-4,1.0]</td>
</tr>
</tbody>
</table>

#### LHLH Case

<table>
<thead>
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<th>parameter</th>
<th>range</th>
<th>parameter</th>
<th>range</th>
</tr>
</thead>
<tbody>
<tr>
<td>$c_{L_1}$</td>
<td>[-1.5,-1.15]</td>
<td>$c_{E_1}$</td>
<td>[2.8,4.0]</td>
</tr>
<tr>
<td>$c_{L_2}$</td>
<td>[-1.5,-0.97]</td>
<td>$c_{E_2}$</td>
<td>[1.8,2.4]</td>
</tr>
<tr>
<td>$c_{L_3}$</td>
<td>[-1.5,-1.22]</td>
<td>$c_{E_3}$</td>
<td>[1.2,1.69]</td>
</tr>
</tbody>
</table>
SUSY Set up

The 5D action is given by

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

The 4D superpotential is given by with only zero modes

\[
\mathcal{W}^{(4)} = \int dy e^{-3ky} \left( e^{\left(\frac{3}{2} - c_{q_i}\right)ky} e^{\left(\frac{3}{2} - c_{u_j}\right)ky} Y_{ij}^u H_U Q_i U_j + e^{\left(\frac{3}{2} - c_{d_j}\right)ky} e^{\left(\frac{3}{2} - c_{q_i}\right)ky} Y_{ij}^d H_D Q_i D_j 
\right.
\]

\[
\left. + e^{\left(\frac{3}{2} - c_{L_i}\right)ky} e^{\left(\frac{3}{2} - c_{E_j}\right)ky} Y_{ij}^E H_D L_i E_j + \ldots \right) \delta(y - \pi R)
\]

\[
\xi(c_i) = \sqrt{\frac{(0.5 - c_i)}{e^{(1-2c_i)\pi kR} - 1}}
\]

c are the bulk mass parameters
Results for MSSM

<table>
<thead>
<tr>
<th>parameter</th>
<th>range</th>
<th>parameter</th>
<th>range</th>
<th>parameter</th>
<th>range</th>
</tr>
</thead>
<tbody>
<tr>
<td>$c_{Q_1}$</td>
<td>[-0.16,3.12]</td>
<td>$c_{D_1}$</td>
<td>[-0.5,4]</td>
<td>$c_{U_1}$</td>
<td>[-1.6,4.0]</td>
</tr>
<tr>
<td>$c_{Q_2}$</td>
<td>[-1.32,2.34]</td>
<td>$c_{D_2}$</td>
<td>[-1.9,2.5]</td>
<td>$c_{U_2}$</td>
<td>[-2,2.4]</td>
</tr>
<tr>
<td>$c_{Q_3}$</td>
<td>[-3,1]</td>
<td>$c_{D_3}$</td>
<td>[-2,1.7]</td>
<td>$c_{U_3}$</td>
<td>[-4,1.0]</td>
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</table>

**Dirac Neutrinos**

<table>
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<tr>
<th>parameter</th>
<th>range</th>
<th>parameter</th>
<th>range</th>
<th>parameter</th>
<th>range</th>
</tr>
</thead>
<tbody>
<tr>
<td>$c_{L_1}$</td>
<td>[-1,2.6]</td>
<td>$c_{E_1}$</td>
<td>[-0.86,3.46]</td>
<td>$c_{N_1}$</td>
<td>[5.68,8.9]</td>
</tr>
<tr>
<td>$c_{L_2}$</td>
<td>[-0.99,2.21]</td>
<td>$c_{E_2}$</td>
<td>[-1,2.24]</td>
<td>$c_{N_2}$</td>
<td>[5.67,8.99]</td>
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<tr>
<td>$c_{L_3}$</td>
<td>[-1,1.54]</td>
<td>$c_{E_3}$</td>
<td>[-1,1.49]</td>
<td>$c_{N_3}$</td>
<td>[5.64,8.99]</td>
</tr>
</tbody>
</table>

**LHLH case**

<table>
<thead>
<tr>
<th>parameter</th>
<th>range</th>
<th>parameter</th>
<th>range</th>
</tr>
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<tbody>
<tr>
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<td>[-1.5,-0.22]</td>
<td>$c_{E_1}$</td>
<td>[2.6,3.7]</td>
</tr>
<tr>
<td>$c_{L_2}$</td>
<td>[-1.5,0.08]</td>
<td>$c_{E_2}$</td>
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<tr>
<td>$c_{L_3}$</td>
<td>[-1.5,0.04]</td>
<td>$c_{E_3}$</td>
<td>[1.1,1.8]</td>
</tr>
</tbody>
</table>
SUSY Breaking

scalar masses

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

trilinear terms

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

gaugino masses

\[m_{1/2} = f m_{3/2}\]

are fermion mass localisation dependent
**Example Point**

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

| (ij) | $|\delta^Q_{LL}|$ | $|\delta^U_{LL}|$ | $|\delta^D_{LR}|$ | $|\delta^U_{LR}|$ | $|\delta^D_{RL}|$ | $|\delta^U_{RL}|$ | $|\delta^D_{RR}|$ | $|\delta^E_{RR}|$ | $|\delta^U_{RR}|$ |
|------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| 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
Higgs fields localisation has now choices

- 1) Both at UV
- 2) Both at IR
- 3) $H_{\text{up}}$ at UV and $H_{\text{down}}$ at IR
- 4) $H_{\text{down}}$ at UV and $H_{\text{up}}$ at IR

$M_{\text{Planck}}$ $M_{\text{GUT}}$

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

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

$\left( M_F \right)_{ij} = v_{u,d} \left( Y_{ij} \pi \left( b_{u,d} - c_i - c_j' \right) k r \pi + Y^{0} \right) \xi(c_{i}) \xi(c_{j}') \zeta_{\Phi}(b_{u,d})$

lot of freedom? ... but

wave functions of fermion fields

wave functions of Higgs fields
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.
only the overlap region is valid

\[ \sum e_i \]

\[ \sum L_i \]

TABLE IV: Example point of the bulk mass parameters which satisfy both fermion mass fits and unification condition for Configuration 3.

<table>
<thead>
<tr>
<th>Hadron parameter</th>
<th>Value</th>
<th>Lepton parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$c_{Q_1}$</td>
<td>-2.3225</td>
<td>$c_{L_1}$</td>
<td>0.5000</td>
</tr>
<tr>
<td>$c_{Q_2}$</td>
<td>-1.0980</td>
<td>$c_{L_2}$</td>
<td>0.4990</td>
</tr>
<tr>
<td>$c_{Q_3}$</td>
<td>-0.0422</td>
<td>$c_{L_3}$</td>
<td>-1.5000</td>
</tr>
<tr>
<td>$c_{D_1}$</td>
<td>3.2696</td>
<td>$c_{E_1}$</td>
<td>3.4333</td>
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<tr>
<td>$c_{D_2}$</td>
<td>2.8534</td>
<td>$c_{E_2}$</td>
<td>2.2879</td>
</tr>
<tr>
<td>$c_{D_3}$</td>
<td>1.7136</td>
<td>$c_{E_3}$</td>
<td>1.0803</td>
</tr>
<tr>
<td>$c_{U_1}$</td>
<td>3.0093</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$c_{U_2}$</td>
<td>1.8657</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$c_{U_3}$</td>
<td>1.2515</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

We now proceed towards determining the low energy supersymmetric spectrum for each of the four configurations.
supersymmetry breaking contributions

universal contribution from 5D sugra

\[ m_{tachyonic}^2(c_m, c_s) = -2m_{3/2}^2 (1 + 2\alpha_{ms}) \quad \text{where} \]
\[ 1 + 2\alpha_{ms} = \frac{(1 - 2c_m)(2 - 2c_s)}{2(4 - 2c_m - 2c_s)} \left( \frac{(1 - \epsilon^{3-2c_m})(1 - \epsilon^{3-2c_s})}{\epsilon^2(1 - \epsilon^{1-2c_m})(1 - \epsilon^{1-2c_s})} - 1 \right) \]

non tachyonic sources

\[ m_{ij}^2 = m_{3/2}^2 r^2 \hat{m}_{ij} \left( \xi_{UV}(c_i) \xi_{UV}(c_j) \xi_{UV}^2(c_S) + \frac{1}{\epsilon^2} \xi_{IR}(c_i) \xi_{IR}(c_j) \xi_{IR}^2(c_S) \right) \]
\[ M_{1,2,3} = m_{3/2} r^{3/2} \hat{M}_{1,2,3} \left( \xi_{UV} + \xi_{UV} \epsilon^{c_S - 1.5} \right) \]
\[ A_{ijh} = m_{3/2} r^2 \hat{A}_{ij} \left( \xi_{UV}(c_i) \xi_{UV}(c_j) \xi_{UV}(c_h) \xi_{UV}(c_S) + \frac{1}{\epsilon} \xi_{IR}(c_i) \xi_{IR}(c_j) \xi_{IR}(c_h) \xi_{IR}(c_S) \right) \]

\[ r = \frac{k}{M_5} \]
\[ c_S \quad \text{SUSY breakingBulk parameter} \]

all flavour dependent
running to the weak scale in flavourful supersymmetry at high scale

$O(1)$ flavour violation at high scale becomes small at weak scale

can lead to $\tau \to \mu + \gamma$ in $10^{-9} - 10^{-10}$ in BR.
Due to the smallness of the diagonal elements, Figure 6 and 7 shows the running of the hadronic and the leptonic parameter. The one loop beta function for the slepton is dominated where the soft mass matrix $\tilde{m}$ is less than 

$\tilde{m} = 3.56 \text{ TeV}, \mu = 2.36 \text{ TeV}, \tan \beta = 25$

<table>
<thead>
<tr>
<th>Mass(TeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\tilde{l}_1$</td>
</tr>
<tr>
<td>$\tilde{b}_1$</td>
</tr>
<tr>
<td>$\tilde{b}_2$</td>
</tr>
<tr>
<td>$\tilde{t}_1$</td>
</tr>
<tr>
<td>$\tilde{\mu}_R$</td>
</tr>
<tr>
<td>$\tilde{\mu}_L$</td>
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<tr>
<td>$\tilde{\nu}_\tau$</td>
</tr>
<tr>
<td>$\tilde{\nu}_\mu$</td>
</tr>
<tr>
<td>$\tilde{\nu}_e$</td>
</tr>
<tr>
<td>$\tilde{N}_1$</td>
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<td>$\tilde{N}_3$</td>
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<tr>
<td>$\tilde{C}_1$</td>
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<tr>
<td>$\tilde{C}_2$</td>
</tr>
<tr>
<td>$m_{A_0}$</td>
</tr>
<tr>
<td>$m_{H^\pm}$</td>
</tr>
<tr>
<td>$m_H$</td>
</tr>
<tr>
<td>$m_H$</td>
</tr>
</tbody>
</table>
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.