Exploring Flavour Violation in an A_4 SUSY GUT

J. Bernigaud†, B. Herrmann†, S. F. King⋆ and **S. J. Rowley**⋆[1]

†LAPTh-Université Savoie Mont Blanc, ⋆SHEP-University of Southampton

Introduction

Many MSSM analyses assume the Minimal Flavour Violation (MFV) paradigm, where the soft-breaking matrices are diagonal in flavour. We relax this assumption and explore the parameter space in the Non-Minimal Flavour Violation (NMFV) scenario. Utilising $A_4\times$SU(5) symmetry uncovers interesting interplay between flaour violating parameters.

SUSY Breaking and SU(5)

Viable SUSY in nature must be broken. The soft-breaking Lagrangian in the MSSM contains the following terms that are crucial for flavour violation:

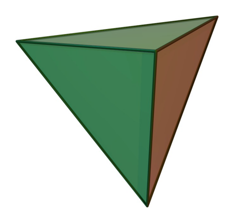
$$\mathcal{L}_{\text{soft}} \supset -\frac{1}{2}\left(M_1\widetilde{B}\widetilde{B} + M_2\widetilde{W}\widetilde{W} + M_3\widetilde{g}\widetilde{g} + \text{h.c.}\right)$$
$$- M_Q^2\widetilde{Q}^\dagger\widetilde{Q} - M_L^2\widetilde{L}^\dagger\widetilde{L} - M_U^2\widetilde{U}^*\widetilde{U} - M_D^2\widetilde{D}^*\widetilde{D} - M_E^2\widetilde{E}^*\widetilde{E}$$
$$- \left(A_U\widetilde{U}H_u\widetilde{Q} + A_D\widetilde{D}H_d\widetilde{Q} + A_E\widetilde{E}H_d\widetilde{L} + \text{h.c.}\right)$$

Unification is achieved through the following representations of SU(5) and A_4:

SU(5)

$$F = \overline{\mathbf{5}} = \begin{pmatrix} d_r^c \\ d_b^c \\ d_g^c \\ e^- \\ -\nu_e \end{pmatrix}_L, \quad T = \mathbf{10} = \begin{pmatrix} 0 & u_g^c & -u_b^c & u_r & d_r \\ . & 0 & u_r^c & u_b & d_b \\ . & . & 0 & u_g & d_g \\ . & . & . & 0 & e^c \\ . & . & . & . & 0 \end{pmatrix}_L$$

A_4



$F = \mathbf{3}$, $T = \mathbf{1}$

Which in turn gives equivalences between SUSY-breaking matrices at the GUT scale:

$$\begin{aligned} M_Q = M_U = M_E &\equiv M_T \\ M_D = M_L &\equiv M_F \\ A_D = (A_E)^T &\equiv A_{FT} \\ A_U &\equiv A_{TT} \end{aligned}$$

$\overline{\mathbf{5}}$ is a triplet of A_4 that unifies the three families, hence $M_F = m_F \cdot \mathcal{I}_3$. There are three $\mathbf{10}$s, each singlets of A_4, so the diagonal elements of M_T are not identical.

We define NMFV parameters in the usual way: Off-diagonal (flavour-violating) elements of the SUSY-breaking matrices are normalised to diagonal elements:

$$(\delta^T)_{ij} = \frac{(M_T)^2_{ij}}{(M_T)_{ii}(M_T)_{jj}}, \qquad (\delta^F)_{ij} = \frac{(M_F)^2_{ij}}{(M_F)_{ii}(M_F)_{jj}}$$
$$(\delta^{TT})_{ij} = \frac{v_u}{\sqrt{2}}\frac{(A_{TT})_{ij}}{(M_T)_{ii}(M_T)_{jj}}, \qquad (\delta^{FT})_{ij} = \frac{v_d}{\sqrt{2}}\frac{(A_{FT})_{ij}}{(M_T)_{ii}(M_F)_{jj}}$$

NMFV Parameter Scan

- We start from the fixed MFV scenarios in Table 1 and perform a random scan over all NMFV parameters simultaneously

	m_F	$(M_T)_{11}$	$(M_T)_{22}$	$(M_T)_{33}$	$(A_{TT})_{33}$	$(A_{FT})_{33}$	M_1	M_2	M_3	$\tan\beta$
Scenario 1	5000	5000	200.0	2995	-940	-1966	250	415.2	2551.6	30
Scenario 2	5000	5000	233.2	2995	-940	-1966	600	415.2	2551.6	30

Table 1: Fixed MFV parameter points, dimensionful parameters given in GeV

- Each NMFV parameter is assumed to have a flat prior and limits of the scan are informed by previous work[1].

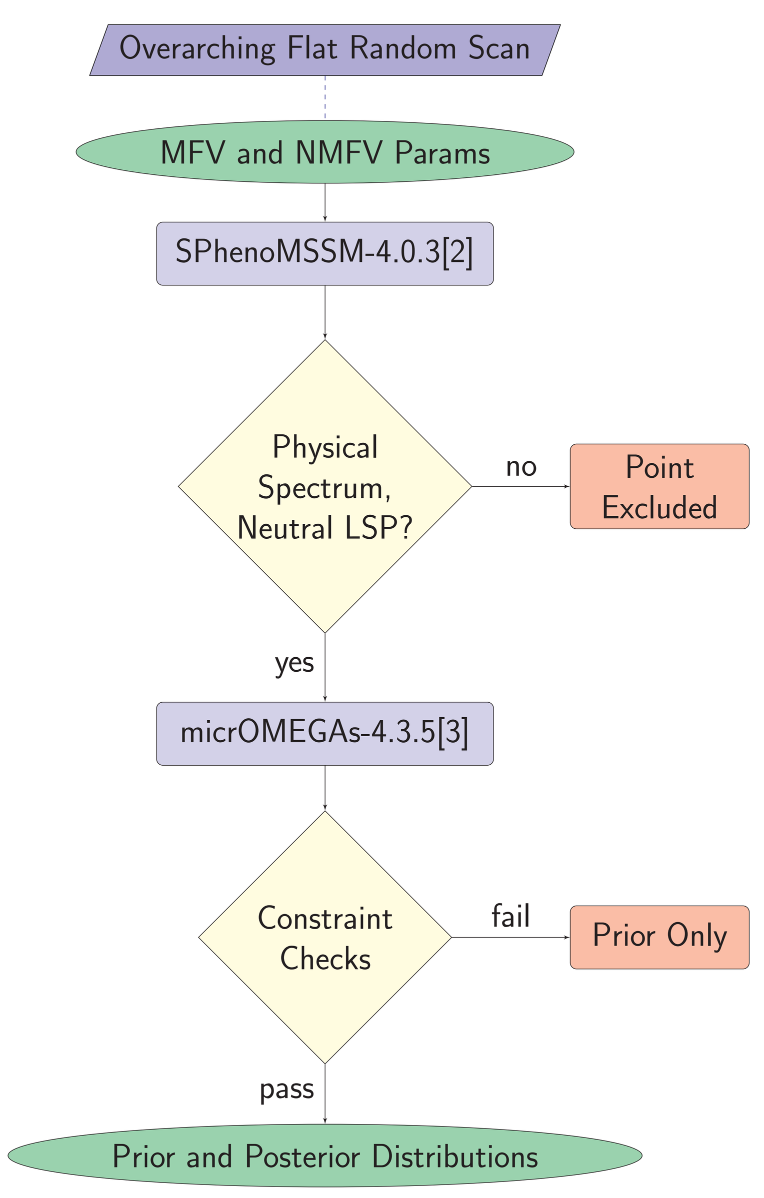


Figure 1: Proceedure for each parameter point

Observable	*Constraint*
m_h	(125.2 ± 2.5) GeV
$\text{BR}(\mu \to e\gamma)$	$< 4.2 \times 10^{-13}$
$\text{BR}(\mu \to 3e)$	$< 1.0 \times 10^{-12}$
$\text{BR}(\tau \to e\gamma)$	$< 3.3 \times 10^{-8}$
$\text{BR}(\tau \to \mu\gamma)$	$< 4.4 \times 10^{-8}$
$\text{BR}(\tau \to 3e)$	$< 2.7 \times 10^{-8}$
$\text{BR}(\tau \to 3\mu)$	$< 2.1 \times 10^{-8}$
$\text{BR}(\tau \to e^-\mu\mu)$	$< 2.7 \times 10^{-8}$
$\text{BR}(\tau \to e^+\mu\mu)$	$< 1.7 \times 10^{-8}$
$\text{BR}(\tau \to \mu^- ee)$	$< 1.8 \times 10^{-8}$
$\text{BR}(\tau \to \mu^+ ee)$	$< 1.5 \times 10^{-8}$
$\text{BR}(B \to X_s\gamma)$	$(3.32 \pm 0.18) \times 10^{-4}$
$\text{BR}(B_s \to \mu\mu)$	$(2.7 \pm 1.2) \times 10^{-9}$
ΔM_{B_s}	$(17.757 \pm 0.312)\ \hbar s^{-1}$
ΔM_K	$(3.1 \pm 1.2) \times 10^{-15}$ GeV
ϵ_K	2.228 ± 0.29
$\Omega_{\text{CDM}}h^2$	0.1198 ± 0.0042

Table 2: Experimental constraints

- Predictions for each parameter point are evaluated as per Figure 1, these are tested against the constraints in Table 2.

Results

Table 3 shows the limits on the NMFV parameters in our chosen scenario. We detail which data from Table 2 have the most constraining effect on each parameter

Parameters	*Scenario 1*	*Scenario 2*	*Principle Constraints*
$(\delta^T)_{12}$	[-0.015, 0.015]	[-0.12, 0.12]	$\Omega_{\tilde{\chi}_1^0}h^2$, $\mu \to e\gamma$
$(\delta^T)_{13}$	[-0.06, 0.06]	[-0.3, 0.3]	$\Omega_{\tilde{\chi}_1^0}h^2$
$(\delta^T)_{23}$	[0, 0]*	[-0.1, 0.1]	$\Omega_{\tilde{\chi}_1^0}h^2$, $\mu \to 3e$, $\mu \to e\gamma$,
$(\delta^F)_{12}$	[-0.008, 0.008]	[-0.015, 0.015]	$\mu \to 3e$, $\mu \to e\gamma$
$(\delta^F)_{13}$	[-0.01, 0.01]	[-0.15, 0.15]	$\mu \to 3e$, $\mu \to e\gamma$
$(\delta^F)_{23}$	[-0.015, 0.015]	[-0.15, 0.15]	$\Omega_{\tilde{\chi}_1^0}h^2$, $\mu \to e\gamma$, $\mu \to 3e$
$(\delta^{TT})_{12}$	[-3, 3.5] $\times 10^{-5}$	[-1, 1.5] $\times 10^{-3}$	LSP, Spectrum, $\Omega_{\tilde{\chi}_1^0}h^2$
$(\delta^{TT})_{13}$	[-6, 7] $\times 10^{-5}$	[-4, 2.5] $\times 10^{-3}$	LSP, Spectrum, $\Omega_{\tilde{\chi}_1^0}h^2$
$(\delta^{TT})_{23}$	[0.5, 4] $\times 10^{-5}$	[-0.25, 0.2]	LSP, Spectrum, $\Omega_{\tilde{\chi}_1^0}h^2$
$(\delta^{FT})_{12}$	[-0.0015, 0.0015]	[-1.2, 1.2] $\times 10^{-4}$	$\mu \to 3e$, $\Omega_{\tilde{\chi}_1^0}h^2$, $\mu \to e\gamma$
$(\delta^{FT})_{13}$	[-0.002, 0.002]	[-5, 5] $\times 10^{-4}$	$\Omega_{\tilde{\chi}_1^0}h^2$, $\mu \to 3e$, $\mu \to e\gamma$
$(\delta^{FT})_{21}$	[0,0]*	[-1.2, 1.2] $\times 10^{-4}$	$\Omega_{\tilde{\chi}_1^0}h^2$, LSP, Spectrum
$(\delta^{FT})_{23}$	[-0.0022, 0.0022]	[-6, 6] $\times 10^{-4}$	$\mu \to 3e$, $\Omega_{\tilde{\chi}_1^0}h^2$, $\mu \to e\gamma$
$(\delta^{FT})_{31}$	[-0.0004, 0.0004]	[-2, 2] $\times 10^{-4}$	$\Omega_{\tilde{\chi}_1^0}h^2$
$(\delta^{FT})_{32}$	[0,0]*	[-1.5, 1.5] $\times 10^{-4}$	$\Omega_{\tilde{\chi}_1^0}h^2$

Table 3: Estimated allowed GUT scale flavour violation for both reference scenarios and impactful constraints. *parameters fixed to 0 else we encounter tachyonic masses/charged DM candidate

The relic density features abundantly; **coannihilation effects are critical** in such scenarios and small NMFV parameters can alter masses of superpartners and give rise to excluded coannihilation cross-sections.

Parameter Correlations

In Figure 2 we see a **strong correlation** between $(\delta^F)_{12}$ and $(\delta^{FT})_{12}$ in those points allowed by the constraints.

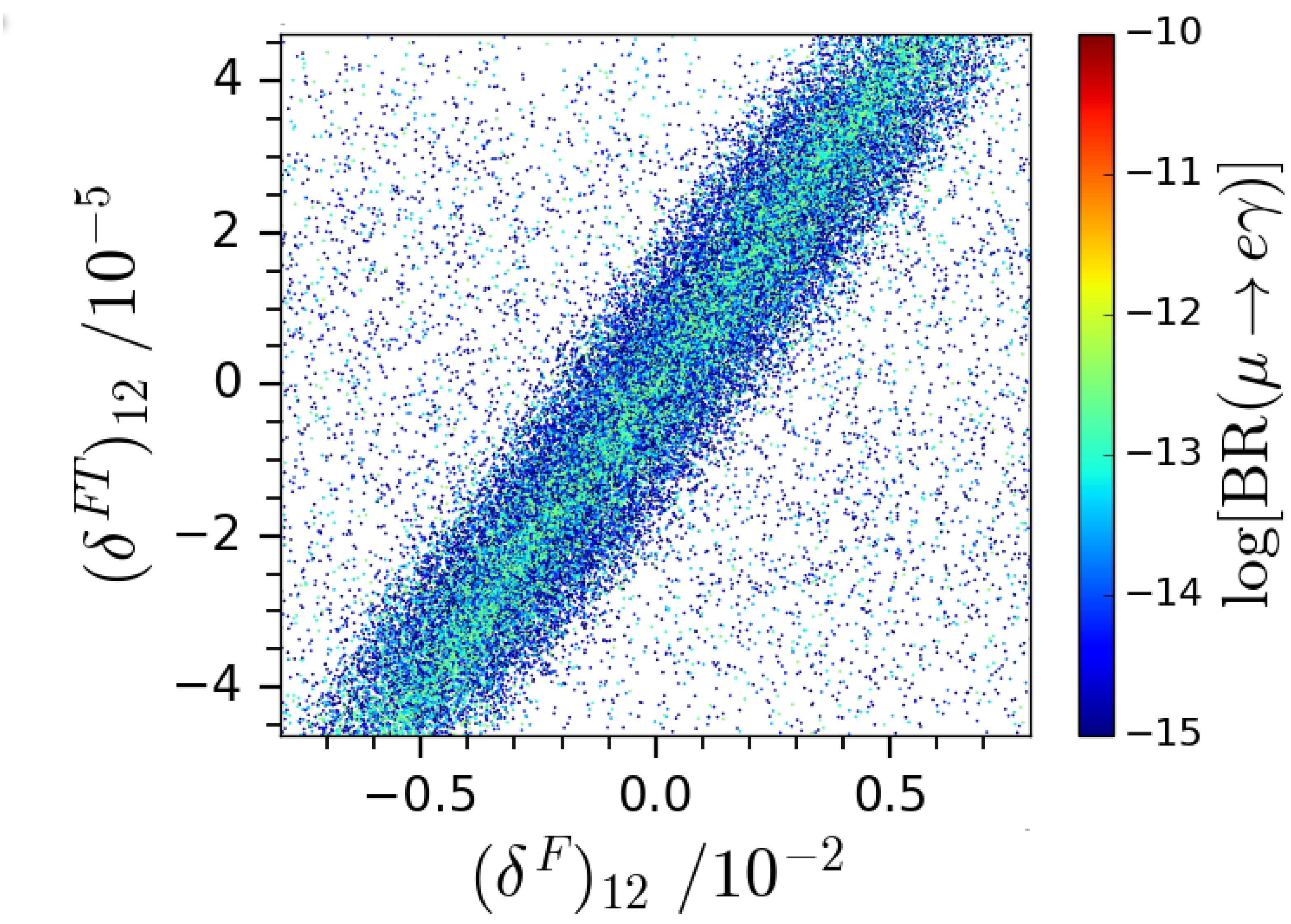


Figure 2: Correlation between two GUT scale parameters from allowed points of Scenario 1

This correlation can be attributed to cancellations in the calculation of $\mu \to e\gamma$ that admit larger regions of parameter space than are allowed when scanning over each δ individually.

Conclusions

- Lepton flavour violation experiments and the DM relic density impose the most stringent constraints on SU(5) MSSM NMFV parameters
- Limits were determined on the allowed departure from MFV in this scenario

Outlook

- Bounds placed on NMFV parameters can inform model building
- Observing flavour patterns at experiments could hint at SU(5) unification

References

[1] A. S. Belyaev, S. F. King and P. B. Schaefers, Phys. Rev. D **97** (2018) no.11, 115002 [arXiv:1801.00514 [hep-ph]].

[2] W. Porod, Comput. Phys. Commun. **153** (2003) 275 [hep-ph/0301101].

[3] G. Bélanger, F. Boudjema, A. Pukhov and A. Semenov, Comput. Phys. Commun. **149** (2002) 103 [hep-ph/0112278].

[1] S.Rowley@soton.ac.uk

based on Bernigaud et.al. JHEP 1903 (2019) **067** [arXiv:1812.07463]