Exploring Flavour Violation in an A_4-Inspired SUSY GUT

J. Bernigaud[1], B. Herrmann[1], S.F. King[2] and **Sam Rowley**[2]

[1]LAPTh, Univ. Grenoble Alpes, USMB, CNRS, 74000 Annecy, France
[2]SHEP Group, School of Physics and Astronomy, University of Southampton, UK

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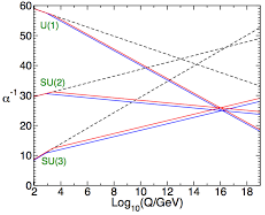
Motivation

$A_4 \times SU(5)$ SUSY GUT

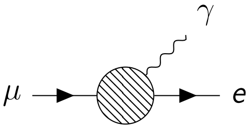
- MSSM informed by high scale S_4 and $SU(5)$ unification
- Minimal symmetry group
- DM candidate, rich phenomenology



Gauge couplings unify in MSSM[1]

Why flavour physics?

- Experimental results could hint at departure from SM
- Model can predicts small violation - compatible?



[1] S. Martin, *"A Supersymmetry primer"*, Adv. Ser. Direct. High Energy Phys **18** (1998), hep-ph/9709356

Breaking Supersymmetry

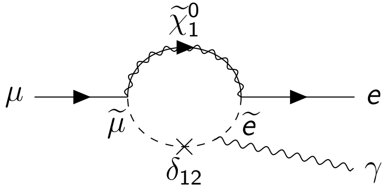
General soft-breaking Lagrangian in the MSSM:

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

Parameters M_Q, M_L A_U etc. are **3x3 matrices** in ‘flavour space’

"Non-Minimal Flavour Violation"

$$(\delta_{LL}^L)_{ij} = \frac{(M_L^2)_{ij}}{(M_L)_{ii}(M_L)_{jj}}$$



The Model

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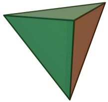
$\mathbf{SU(5)}$	$\times$	$\mathbf{A_4}$

$$\underbrace{SU(3)_C \times SU(2)_L \times U(1)_Y}_{\mathrm{SU(5)}}$$

$$\left.\begin{matrix} F_1 \\ F_2 \\ F_3 \end{matrix}\right\} \mathbf{3}$$



$$F(\bar{\mathbf{5}}) = d^R_{r,g,b} \oplus L$$
$$T(\mathbf{10}) = u^R_{r,g,b} \oplus Q_{r,g,b} \oplus e^R$$

Break discrete symmetry $\implies$ *Flavour violation predictions*

$A_4 \times SU(5)$ —GUT Scale→ MSSM —SUSY Scale→ SM

15 NMFV parameters in GUT-informed MSSM $(\delta^T, \delta^F, \delta^{FT}, \delta^{TT})$

NMFV Parameter Scan

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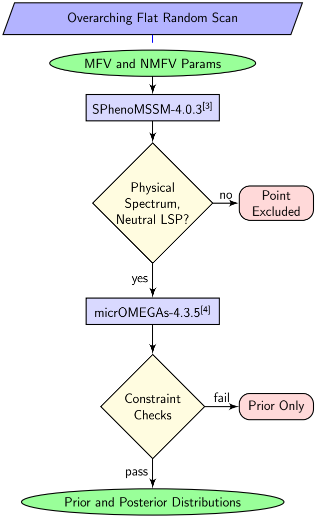

Observable	Constraint
m_h	(125.2 ± 2.5) GeV
$\mathrm{BR}(\mu \to e\gamma)$	$< 4.2 \times 10^{-13}$
$\mathrm{BR}(\mu \to 3e)$	$< 1.0 \times 10^{-12}$
$\mathrm{BR}(\tau \to e\gamma)$	$< 3.3 \times 10^{-8}$
$\mathrm{BR}(\tau \to \mu\gamma)$	$< 4.4 \times 10^{-8}$
$\mathrm{BR}(\tau \to 3e)$	$< 2.7 \times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

Table: Experimental constraints imposed on the $A_4 \times SU(5)$ parameter space in our study.

[3] W. Porod, *"SPheno..."*, Comput. Phys. Commun. **153** (2003), hep-ph/0301101

[4] G.Belanger et. al., *"MicrOMEGAs..."*, Comput. Phys. Commun. **149** (2002), hp-ph/0112278

Summary of Constraints

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Parameters	*Scenario 1:* $m_{\tilde{\mu}} \simeq 105\,GeV$	*Scenario 2:* $m_{\tilde{\mu}} \simeq 250\,GeV$	*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]† $\times 10^{-3}$	prior, $\Omega_{\tilde{\chi}_1^0} h^2$
$(\delta^{TT})_{13}$	[-6, 7]† $\times 10^{-5}$	[-4, 2.5]† $\times 10^{-3}$	prior, $\Omega_{\tilde{\chi}_1^0} h^2$
$(\delta^{TT})_{23}$	[-0.5, 4]† $\times 10^{-5}$	[-0.25, 0.2]†	prior, $\Omega_{\tilde{\chi}_1^0} h^2$
$(\delta^{FT})_{12}$	[-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]† $\times 10^{-4}$	$\Omega_{\tilde{\chi}_1^0} h^2$, prior
$(\delta^{FT})_{23}$	[-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: GUT-scale flavour-violation limits and impactful constraints.

Results

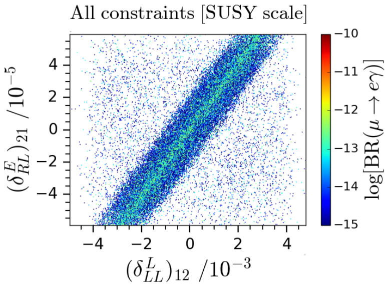

Figure: Correlations broaden allowed NMFV

NMFV can alter $m_{\tilde{\mu}}$ and significantly shift relic density

- LFV and DM impose stringent constraints
- Future LHC/LFV data motivate similar studies

Outlook:

- Model descrimination from flavour physics
- Including neutrino phenomenology

Results

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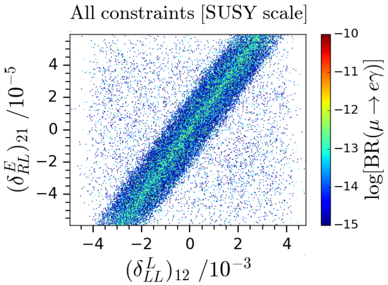

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Thank you for your attention

Backup: SU(5) MSSM Soft Lagrangian

$$
\begin{aligned}
\mathcal{L}_{\text{soft}}^{\text{SU(5)MSSM}} = &-\frac{1}{2}\left(M_1 \widetilde{B}\widetilde{B} + M_2 \widetilde{W}\widetilde{W} + M_3 \widetilde{g}\widetilde{g} + \text{h.c.}\right) \\
&- M_F^2 \widetilde{F}^\dagger \widetilde{F} - M_T^2 \widetilde{T}^\dagger \widetilde{T} \\
&- \left(A_{TT} \widetilde{T}^* H_u \widetilde{T} + A_{FT} \widetilde{F}^* H_d \widetilde{T} + \text{h.c.}\right) \\
&- m_{H_u}^2 H_u^* H_u - m_{H_d}^2 H_d^* H_d - \left(b H_u^* H_d + \text{h.c.}\right).
\end{aligned}
$$

MFV Reference Scenarios

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	Parameter	Scenario 1	Scenario 2
MFV Parameters at GUT scale	m_F	5000	5000
	m_{T_1}	5000	5000
	m_{T_2}	200	233.2
	m_{T_3}	2995	2995
	$(A_{TT})_{33}$	-940	-940
	$(A_{FT})_{33}$	-1966	-1966
	M_1	250.0	600.0
	M_2	415.2	415.2
	M_3	2551.6	2551.6
	m_{H_u}	4242.6	4242.6
	m_{H_d}	4242.6	4242.6
	$\tan\beta$	30	30
	μ	-2163.1	-2246.8

	Observable	Scenario 1	Scenario 2
Physical masses	m_h	126.7	127.3
	$m_{\tilde{g}}$	5570.5	5625.7
	$m_{\tilde{\mu}_L}$	4996.7	4997.5
	$m_{\tilde{\mu}_R}$	102.1	254.4
	$m_{\tilde{\chi}_1^0}$	94.6	250.4
	$m_{\tilde{\chi}_2^0}$	323.6	322.0
	$m_{\tilde{\chi}_3^0}$	2248.8	2331.1
	$m_{\tilde{\chi}_4^0}$	2248.8	2331.2
	$m_{\tilde{\chi}_1^\pm}$	323.8	322.2
	$m_{\tilde{\chi}_2^\pm}$	2249.8	2332.2
	$\Omega_{\tilde{\chi}_1^0} h^2$	0.116	0.120

Backup: Phenomenology

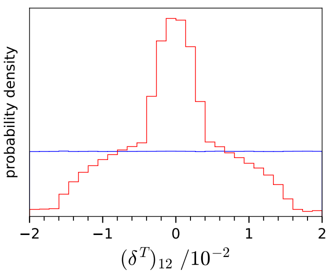


Figure: Prior in blue, posterior in red

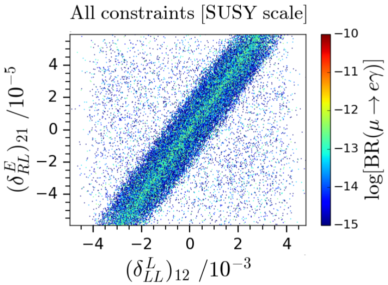


Figure: Correlations between parameters

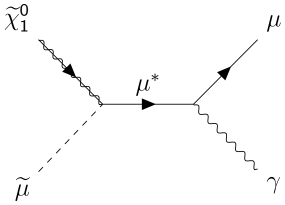


Figure: Co-annihilation channel

Co-annihilation

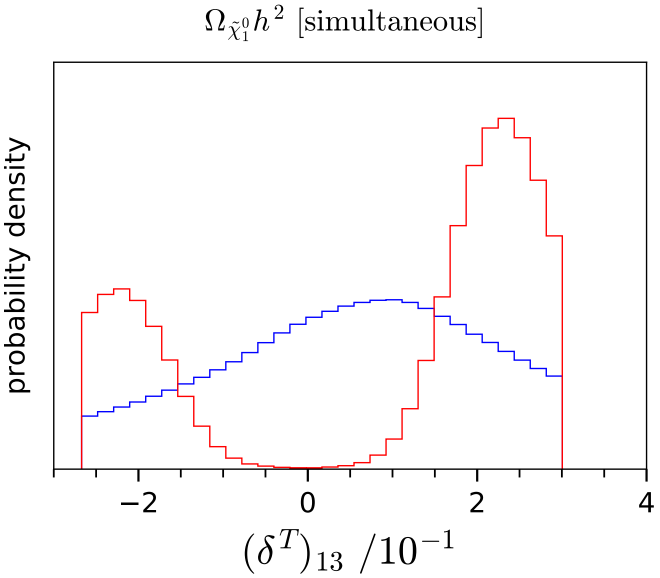
NMFV can alter $m_{\widetilde{\mu}}$ and significantly shift relic density

Backup: Contributions to Ω_{DM}

Annihilation channel	Relative contribution to $\Omega_{\tilde{\chi}_1^0} h^2$	
	Scenario 1	Scenario 2
$\tilde{\chi}_1^0 \, \tilde{\chi}_1^0 \to \mu \, \bar{\mu}$	27%	2%
$\tilde{\chi}_1^0 \, \tilde{\mu}_R \to \mu \, \gamma$	45%	31%
$\tilde{\chi}_1^0 \, \tilde{\mu}_R \to \mu \, Z^0$	8%	8%
$\tilde{\mu}_R \, \tilde{\mu}_R \to \mu \, \mu$	10%	37%
$\tilde{\mu}_R \, \tilde{\mu}_R^* \to \gamma \, \gamma$	3%	11%

Table: Dominant annihilation channels contributing to the annihilation cross-section and the neutralino relic density in the two reference scenarios

Backup: Dark Matter Constraint



Backup: Individual vs. Simultaneous

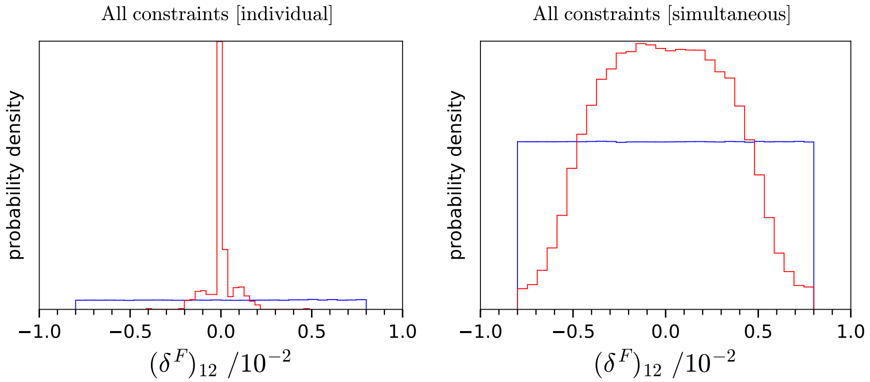


Figure: Comparison of individual (left) vs. simultaneous (right) scan of the NMFV parameter $(\delta^F)_{12}$ around Scenario 1. Each panel shows the prior (blue) together with the posterior (red) distributions.

Backup: SUSY scale δs

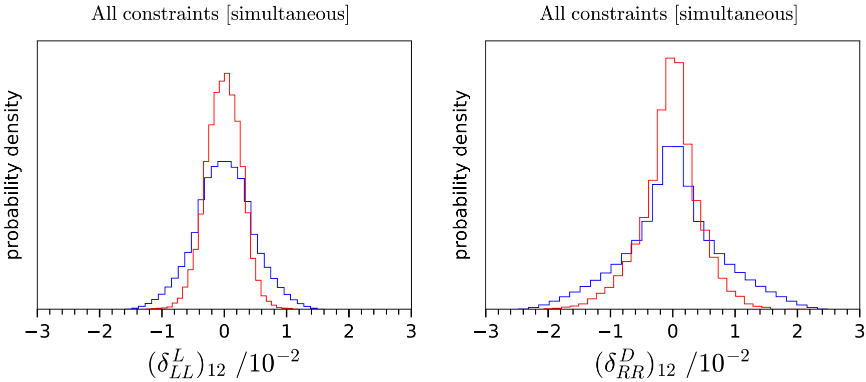


Figure: Distributions obtained for the GUT-scale parameter $(\delta^F)_{12}$; the associated SUSY-scale parameters $(\delta^L_{LL})_{12}$ and $(\delta^D_{RR})_{12}$