SUSY Observables in an $A_4 \times SU(5)$ model of muon $g-2$ and dark matter

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To be published soon... hopefully !

Outline

The $A_4 \times SU(5)$ SUSY model

From : arXiv[1801.00514v1], Alexander S. Belyaev, Setphen F. King et al. (2018)

Representations under $SU(5)$ where $T = \mathbf{10}$ and $F = \overline{\mathbf{5}}$:

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

Under $A_4 \to T = \mathbf{1}$ and $F = \mathbf{3}$

Relations from symmetries (GUT scale)

$$y_u = y_u^\dagger, \quad y_d = y_e^\dagger, \quad A_u = A_u^\dagger, \quad A_d = A_e^\dagger, \quad (m_F)_{ii} = m_F$$

$$m_F \to (M_{\tilde{d}})_{RR} \text{ and } (M_{\tilde{\ell}})_{LL}.$$

$$m_T \to (M_{\tilde{q}})_{LL}, (M_{\tilde{u}})_{RR} \text{ and } (M_{\tilde{\ell}})_{RR}$$

The $A_4 \times SU(5)$ SUSY model

In the SCKM basis*, neglecting the D-terms and SM parameters, the GUT scalars mass matrices are :

$$M^2_{\tilde{d}} = \begin{pmatrix} m_T^2 & A_d^\dagger \\ A_d & m_F^2 \end{pmatrix}, \quad M^2_{\tilde{u}} = \begin{pmatrix} V^\dagger_{CKM} m_T^2 V_{CKM} & V^\dagger_{CKM} A_u^\dagger V_{CKM} \\ V^\dagger_{CKM} A_u V_{CKM} & V^\dagger_{CKM} m_T^2 V_{CKM} \end{pmatrix}$$

$$M^2_{\tilde{\ell}} = M^2_{\tilde{d}} \; (L \longleftrightarrow R)$$

Typical characteristics of the benchmark points (arXiv[1801.00514v1])

- Minimal flavour violation framework
- Really light $\tilde{\mu}_R$, needed for $g-2$.
- Very close $\tilde{\chi}_1^0$ mass, needed for DM relic density.

* *We neglected the running of the CKM, the rotation can be performed either at GUT or SUSY scale.*

Objectives and method

The initial paper (arXiv[1801.00514v1]) focused on $(g-2)_\mu$ and DM and they neglected the off-diagonal elements.

Some reasons to go beyond :

- In general the diagonal elements can be non zero
- This model needs additional particles : flavons. If not $\rightarrow$ No down yukawas/trilinear soft terms allowed.
- Including flavons $\rightarrow$ off-diagonal elements.

Goal

What are the allowed ranges for the flavour violating parameters ?

Objectives and method

$$(\delta_{AA})_{ij} = \frac{(M_{AA})^2_{ij}}{(M_{AA})_{ii}(M_{AA})_{jj}} \text{ with } A = L, R$$

$$(\delta_{RL})_{ij} = \frac{v_{u/d}}{\sqrt{2}} \frac{A_{u/d}}{(M_{RR})_{ii}(M_{LL})_{jj}}$$

The δ parameters at SUSY scale :

$$\Rightarrow \quad \delta^{M_{\tilde{q}}}_{LL},\ \delta^{M_{\tilde{u}}}_{RR},\ \delta^{M_{\tilde{d}}}_{RR},\ \delta^{M_{\tilde{\ell}}}_{LL},\ \delta^{M_{\tilde{\ell}}}_{RR},\ \delta^{M_{\tilde{u}}}_{RL},\ \delta^{M_{\tilde{d}}}_{RL},\ \delta^{M_{\tilde{\ell}}}_{RL}$$

The δ parameters at GUT scale :

- Using the $SU(5)$ relations and the $T,\ F$ notation for the representations we end with the following δ (15 free parameters) :

$$\delta^T,\ \delta^F,\ \delta^{TT},\ \delta^{FT}$$

Objectives and method

1) Initial benchmark point

2) Scan over δ parameters at GUT scale

3) Check leptonic, hadronic and DM relic density constraints.

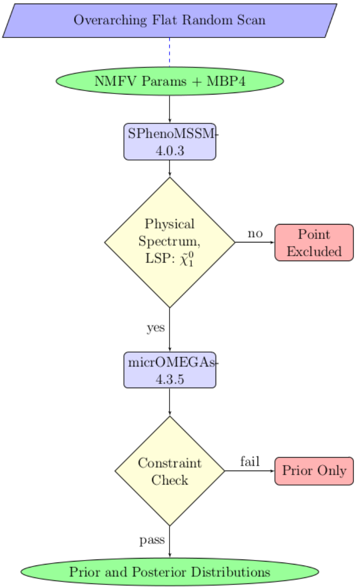
4) Investigate cancellation effects.

We also ran scans over individual δ

Improvements from previous studies

In most of the $SU(5)$ SUSY models, δ scanned once at a time. We performed a simultaneous scan of the δ.

Numerical setup



Observable	Constraint
m_h	(125 ± 2.5) GeV
$\mathrm{BR}(\mu \to e\gamma)$	$< 5.7 \times 10^{-13}$
$\mathrm{BR}(\mu \to 3e)$	$< 1.0 \times 10^{-12}$
$\mathrm{BR}(\tau \to e\gamma)$	$< 3.3 \times 10^{-8}$
$\mathrm{BR}(\tau \to \mu\gamma)$	$< 4.4 \times 10^{-8}$
$\mathrm{BR}(\tau \to 3e)$	$< 2.7 \times 10^{-8}$
$\mathrm{BR}(\tau \to 3\mu)$	$< 2.1 \times 10^{-8}$
$\mathrm{BR}(\tau \to e^-\mu\mu)$	$< 2.7 \times 10^{-8}$
$\mathrm{BR}(\tau \to e^+\mu\mu)$	$< 1.7 \times 10^{-8}$
$\mathrm{BR}(\tau \to \mu^- ee)$	$< 1.8 \times 10^{-8}$
$\mathrm{BR}(\tau \to \mu^+ ee)$	$< 1.5 \times 10^{-8}$
$\mathrm{BR}(B \to X_s\gamma)$	$(3.43 \pm 0.22) \times 10^{-4}$
$\mathrm{BR}(B_s \to \mu\mu)$	$(2.8 \pm 0.7) \times 10^{-9}$
$\mathrm{BR}(B\tau \to \mu\gamma)$	$< 4.4 \times 10^{-8}$
ΔM_{B_s}	(17.65 ± 3.35) ps^{-1}
ϵ_K	2.228 ± 0.29
ΔM_K	$(3.1 \pm 1.6) \times 10^{-15}$ GeV
$\Omega_{CDM} h^2$	0.1198 ± 0.0042

Numerical setup

Slightly different starting point

Not the same version of tools

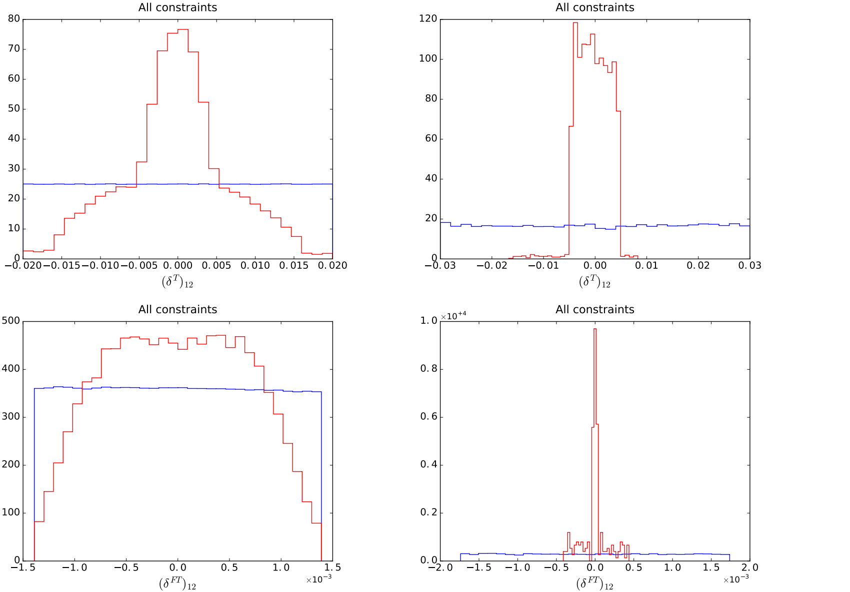
No $(g-2)_\mu$ included in the constraints

- Flavour conserving process $\rightarrow$ small effect from the δ
- We didn't find any reliable tool for $(g-2)_\mu$ in NMFV framework

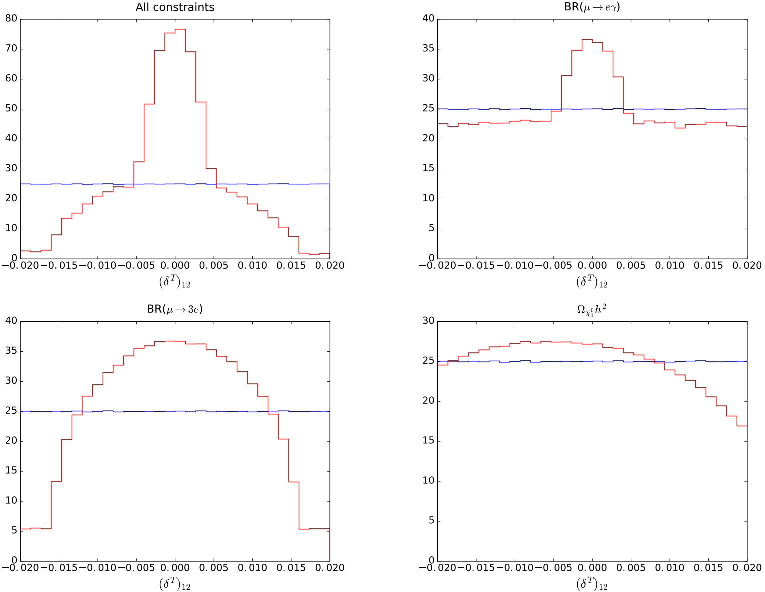
Limitations

- $\tilde{\chi}_1^0$ and $\tilde{\mu}$ masses $\rightarrow$ impacted by δ, leads to set to 0 three of the δ
- Computational time

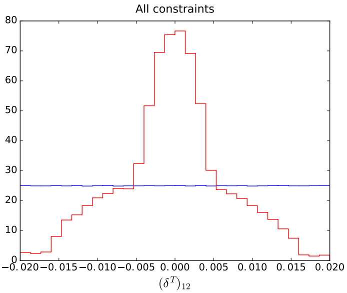
Results : Constraining parameters ranges

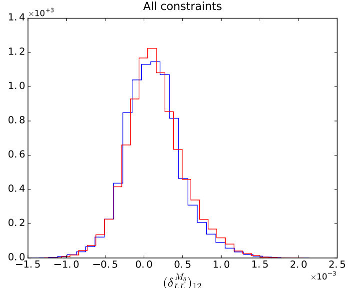


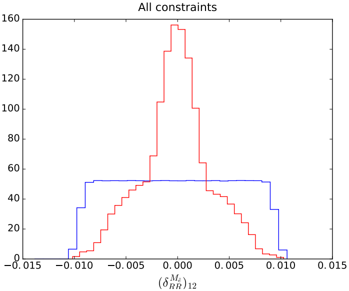
Results : Constraining parameters ranges



Results : Constraining parameters ranges



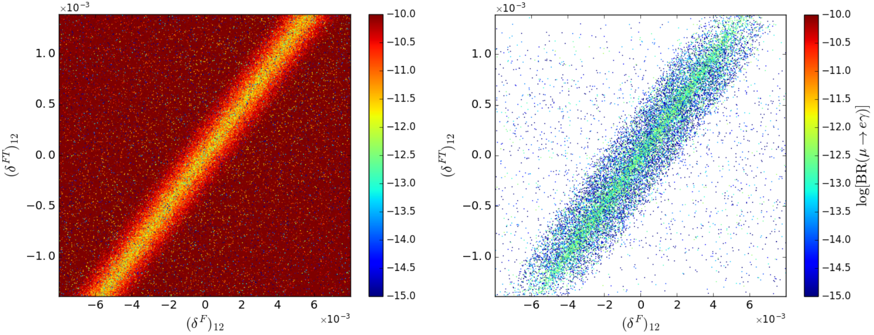




Results : Constraining parameters ranges

Parameters (GUT scale)	Estimated allowed range	Most constraining observables
$(\delta^T)_{12}$	[-0.015, 0.015]	$\mathrm{BR}(\mu \to 3e), \mathrm{BR}(\mu \to e\gamma), \Omega_{\tilde{\chi}_1^0} h^2$
$(\delta^T)_{13}$	]-0.06, 0.06[	$\Omega_{\tilde{\chi}_1^0} h^2$
$(\delta^T)_{23}$	$[0,0]^*$	prior
$(\delta^F)_{12}$	[-0.008, 0.008]	$\mathrm{BR}(\mu \to 3e), \mathrm{BR}(\mu \to e\gamma)$
$(\delta^F)_{13}$	]-0.01, 0.01[	$\mathrm{BR}(\mu \to e\gamma)$
$(\delta^F)_{23}$	]-0.015, 0.015[	$\mathrm{BR}(\mu \to e\gamma), \Omega_{\tilde{\chi}_1^0} h^2$
$(\delta^{TT})_{12}$	[-3, 3.5] $\times 10^{-5}$	prior
$(\delta^{TT})_{13}$	]-6, 7] $\times 10^{-5}$	prior
$(\delta^{TT})_{23}$	]-0.5, 4[$\times 10^{-5}$	prior, $\Omega_{\tilde{\chi}_1^0} h^2$
$(\delta^{FT})_{12}$	[-0.0015, 0.0015]	$\Omega_{\tilde{\chi}_1^0} h^2$
$(\delta^{FT})_{13}$	]-0.002, 0.002[	$\mathrm{BR}(\mu \to e\gamma), \Omega_{\tilde{\chi}_1^0} h^2$
$(\delta^{FT})_{21}$	[0,0]*	prior
$(\delta^{FT})_{23}$	]-0.0022, 0.0022[	$\mathrm{BR}(B \to X_s\gamma), \Omega_{\tilde{\chi}_1^0} h^2$
$(\delta^{FT})_{31}$	]-0.0004, 0.0004[	$\Omega_{\tilde{\chi}_1^0} h^2$
$(\delta^{FT})_{32}$	[0,0]*	prior

Results : Study of cancellations effects



Conclusion

Summary

- We studied the impact of flavour violation parameters on observables in a previous model
- We emphasized the fact that these parameters must be studied together
- We set different limits on the parameters. Help for further model building ?

Currently under investigation

- Extend range of the δ as much as possible
- Investigate physical reasons for the correlation (TeV scale, impact of kinematics...)

Going beyond

- MCMC over the full parameters space in SU(5) (In progress)
- Include neutrinos mass ? (difficult if model independent)
- Analysis of a more complete model (including Flavons, neutrinos) ? *Ex : arXiv[1511.07886], Maria Dimou et al. (2016)*