

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

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Outline

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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 $F = \bar{\mathbf{5}}$:

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

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

Relations from symmetries (GUT scale)

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

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

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

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 :

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

$$M_{\tilde{\ell}}^2 = M_{\tilde{d}}^2 \quad (L \longleftrightarrow R)$$

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

$$(\delta_{AA})_{ij} = \frac{(M_{AA})_{ij}^2}{(M_{AA})_{ii}(M_{AA})_{jj}} \text{ with } A = L, R$$
$$(\delta_{RL})_{ij} = \frac{v_{u/d}}{\sqrt{2}} \frac{A_{u/d}}{(M_{RR})_{ii}(M_{LL})_{jj}}$$

The δ parameters at SUSY scale :

$$\Rightarrow \delta_{LL}^{M_{\bar{q}}}, \delta_{RR}^{M_{\bar{u}}}, \delta_{RR}^{M_{\bar{d}}}, \delta_{LL}^{M_{\bar{\ell}}}, \delta_{RR}^{M_{\bar{\ell}}}, \delta_{RL}^{M_{\bar{u}}}, \delta_{RL}^{M_{\bar{d}}}, \delta_{RL}^{M_{\bar{\ell}}}$$

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

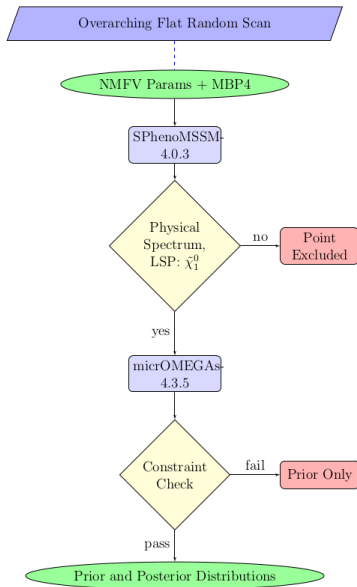
- 1) Initial benchmark point
- 2) Scan over δ parameters at GUT scale
- 3) Check leptonic, hadronic and DM relic density constraints.
- 4) Investigate cancellation effects.

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

Numerical setup

Slightly different starting point

Not the same version of tools

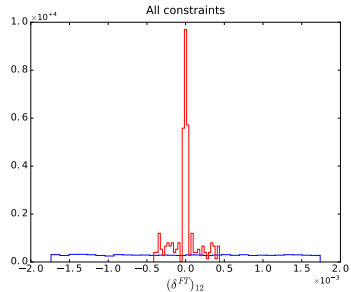
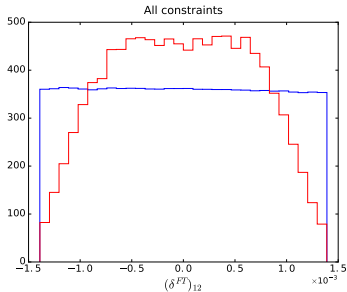
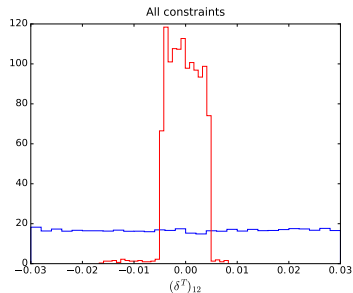
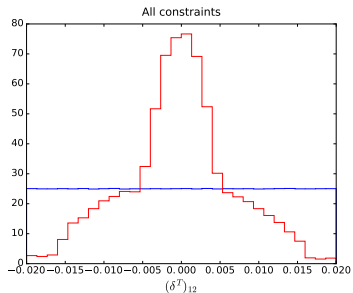
No $(g - 2)_\mu$ included in the constraints

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

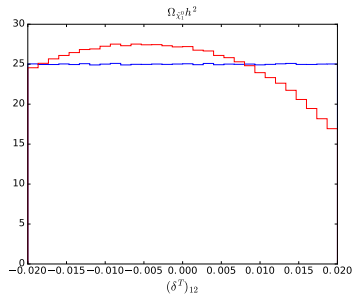
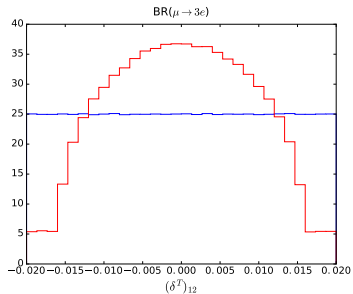
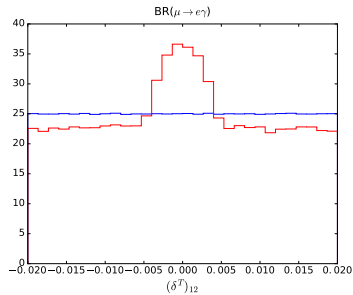
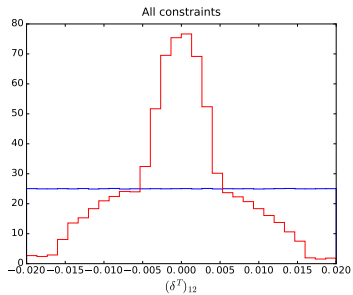
Limitations

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

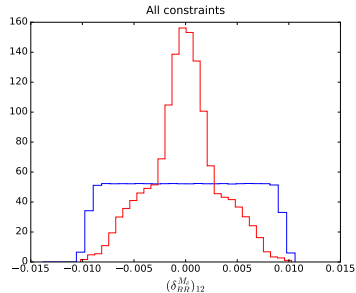
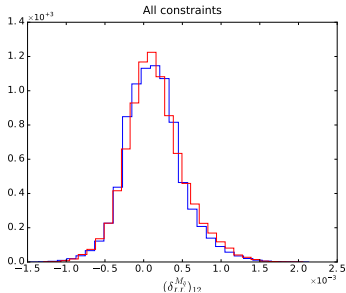
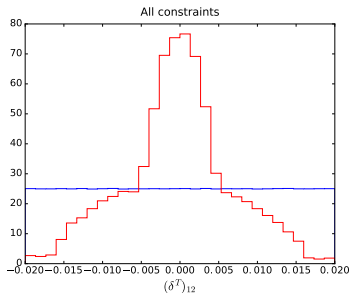
Results : Constraining parameters ranges



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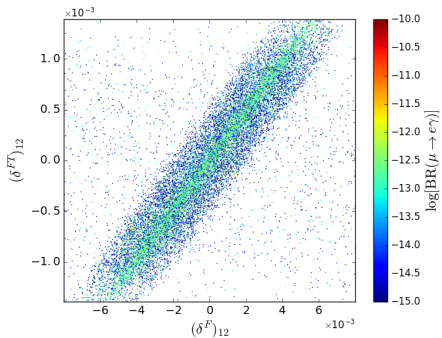
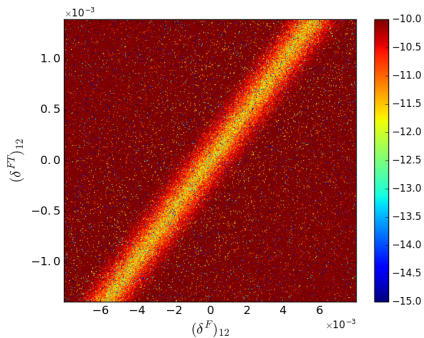
Results : Constraining parameters ranges



Results : Constraining parameters ranges

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