FlexibleSUSY and CLFV

Dominik Stöckinger, TU Dresden

Workshop Lepton Flavour Change in Nuclei — Trento, 17th April 2025

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$\nearrow$ $\nwarrow$

BSM package

now included$\rightsquigarrow$here: examples

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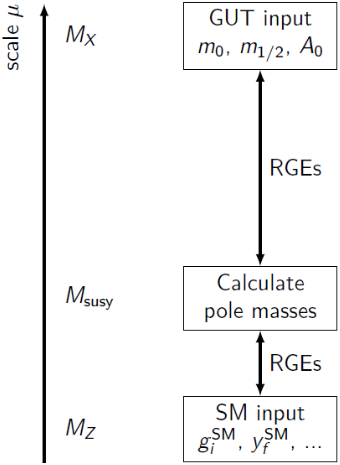
FlexibleSUSY: history, status

- initial idea [Athron, Park, DS, Voigt '14]



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- then, more general

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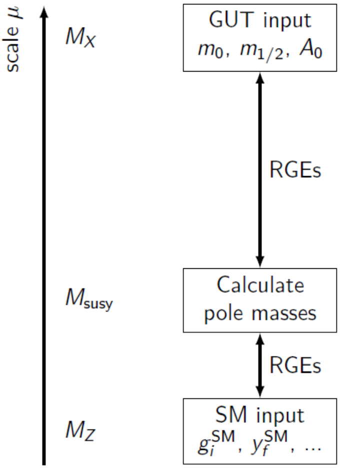

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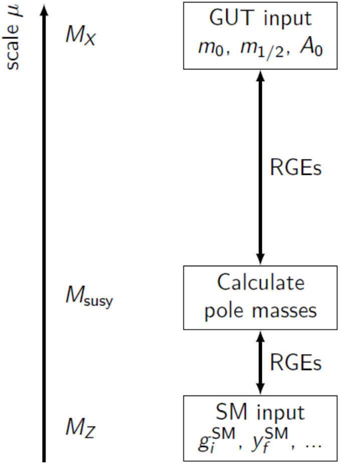
- includes a_μ spin-off GM2Calc (MSSM, 2HDM)
  M_h^{SUSY}
  [...Steudtner '16 ...Kwasnitza '20,'21]
  M_W [...Bach, Kotlarski '22]



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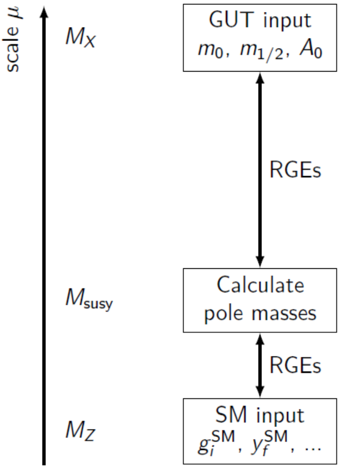
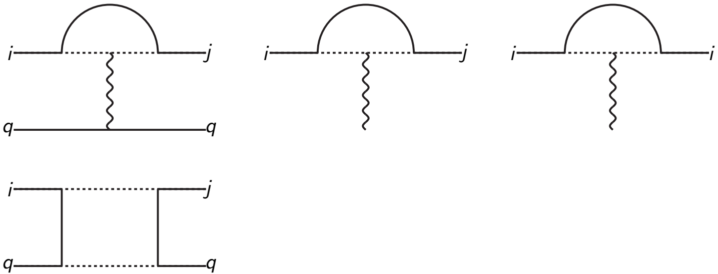
  M_W [. . . Bach, Kotlarski '22]
- now also CLFV
  [. . . Khasianevich, Kotlarski '24]



Observables of interest

muon $(g-2)$

$\mu \to e$ | $\mu \to e\gamma$ | $(g-2)_\mu$



D, A_1^{21}, A_2^{21} | A_2^{21} | A_2^{22}

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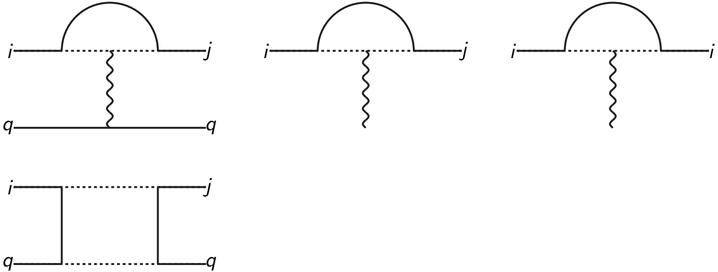

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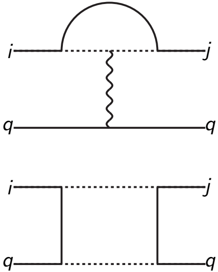

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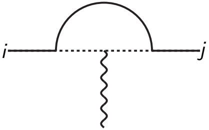

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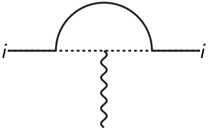

A_2^{22}

Observables of interest

Large Δa_μ or anarchic flavour pattern:

$$BR(\mu \to e\gamma) \approx 4.2 \times 10^{-13} \left[4 \left(\frac{\Delta a_\mu}{10^{-9}} \right)^2 \left(\frac{A_2^{21}}{10^{-4} A_2^{22}} \right)^2 \right]$$

Dipole dominance:

$$BR(\mu \to e(Al)) \approx 0.0027 \times BR(\mu \to e\gamma)$$

In detail: model-specific correlations!

- Leptoquarks: a_μ versus anarchic flavour patterns?
- Grimus-Neufeld: minimal neutrino-mass model — CLFV impact on parameters?
- MRSSM: small a_μ? Unusually large $\mu \to e$?

Example 1: Leptoquarks

Question for LQ model, assuming large a_μ:

how non-universal does the flavour structure have to be?

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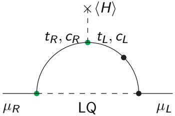
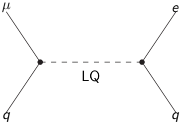
LQ a_μ diagram:



$\propto \lambda^{q2}$ $(q = 2, 3)$

LQ couplings to e, τ lead to $\mu \to e\gamma$, $\tau \to \mu\gamma$, ... $\propto \lambda^{q1}$, λ^{q3}

$\mu \to e$ conversion possible at tree-level



$\propto \lambda^{q1}, \lambda^{q2} (q = 1)$

Explore flavour constraints for LQ

$q\backslash\ell$	e	μ	τ	valid
u	$\lambda_L^{11}\lambda_R^{11}\lambda_L^{12}\lambda_R^{12} < 6.5\cdot 10^{-12} \to 3.7\cdot 10^{-14}$ (spans e and μ)		—	all
	$\lambda_L^{11}(\lambda_R^{12}-0.65) < 2.9\cdot 10^{-6} \to$ $\lambda_L^{11}(\lambda_R^{12}-0.40) < 2.4\cdot 10^{-7}$	$\lambda_L^{12} < 0.82$		
c	$\lambda_L^{21}\lambda_R^{21} < 1.2\cdot 10^{-10} \to 1.8\cdot 10^{-11}$ $\lambda_{L,R}^{21} < 1.3\cdot 10^{-4} \to 5.0\cdot 10^{-5}$ $\lambda_L^{21} < 4.6\cdot 10^{-6} \to 1.7\cdot 10^{-6}$	$0.18 < \lambda_L^{22}\lambda_R^{22} < 0.56$ $5.1\cdot 10^{-2} < \lambda_{L,R}^{22} < \sqrt{4\pi}$ $\lambda_L^{22} < 0.13\,,\ 1.5 < \lambda_R^{22}$	$\lambda_L^{23}\lambda_R^{23} < 2.1\cdot 10^{-2} \to 4.7\cdot 10^{-4}$ $\lambda_{L,R}^{23} < 1.7 \to 0.23$ $\lambda_L^{23} < 6.0\cdot 10^{-2} \to 8.9\cdot 10^{-3}$	sc. 2
t	$\lambda_L^{31}\lambda_R^{31} < 2.1\cdot 10^{-12} \to 2.9\cdot 10^{-13}$ $\lambda_{L,R}^{31} < 1.3\cdot 10^{-4} \to 4.9\cdot 10^{-5}$	$3.1\cdot 10^{-3} < \lambda_L^{32}\lambda_R^{32} < 9.3\cdot 10^{-3}$ $8.7\cdot 10^{-4} < \lambda_{L,R}^{22} < \sqrt{4\pi}$	$\lambda_L^{33}\lambda_R^{33} < 3.5\cdot 10^{-4} \to 7.8\cdot 10^{-6}$ $\lambda_{L,R}^{33} < 1.7 \to 0.25$	sc. 1

[Khasianevich,DS,Stöckinger-Kim,Wünsche '23]

[see also Felipe, Goncalves, Morais et al '22, Hiller et al '16]

muon $g-2$ explained by top-loop

constraint from $\mu \to e\gamma$ (MEG and future MEG-II)

constraint from $\mu \to e$ conversion (SINDRUM and future COMET-I)

LQ couplings must be strongly non-universal!

($\mu \to e\gamma$ constraint would relax by factor 2 if Δa_μ goes down)

Example 2: Grimus-Neufeld model — neutrino mass

minimal model: 2HDM plus single RH neutrino

$$\mathcal{L} \ni M_N \bar{N} N \qquad + y_i \bar{L}_i \Phi_v N \qquad + d_i \bar{L}_i \Phi_\perp N$$

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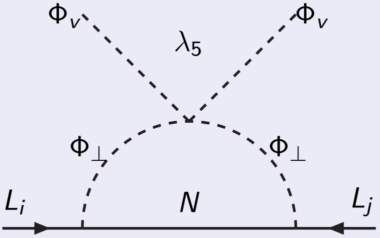
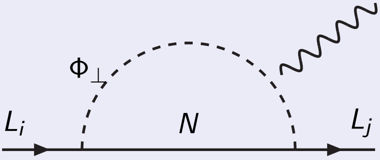


- $m_\nu \sim \lambda_5$ (Z_2-violating!) $\rightsquigarrow$ small $\lambda_5 \Leftrightarrow$ large Yukawas



- danger: $\mu \to e\gamma$, $\tau \to e\gamma \ldots \rightsquigarrow$ interplay Higgs – m_{ν_2} – LFV

Question for GN model:

Given m_{ν_i}: what does LFV imply for the Higgs sector/Z_2-symmetry?

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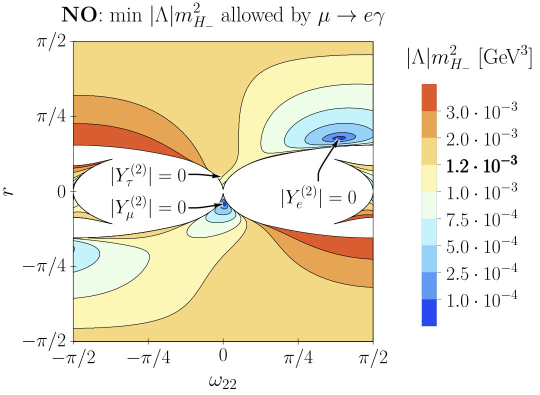


Answer:

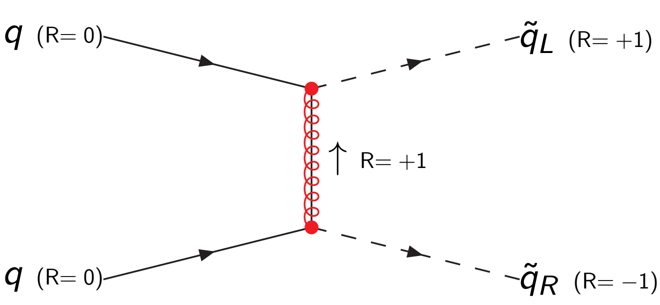
- $\mu \to e\gamma$ strongest constraint and provides lower limits on $\Lambda m_{H_-}^2 \propto \lambda_5$
- except small regions where τ-decays could be observed.

[Dudenas,Gajdosik,Khasianevich,Kotlarski,DS '22]

absolute bound: $|\lambda_5| > 1 \cdot 10^{-2} \frac{\text{keV}}{m_4}$,

typical bound: (no $\tau \to e\gamma/\mu\gamma$ expected): $|\lambda_5| \gtrsim \frac{\text{keV}}{m_4}$.

Example 3: MRSSM [Kribs, Poppitz, Weiner] [Diessner, Kalinowski, Kotlarski, DS '14, '15, '16, '17, '19]



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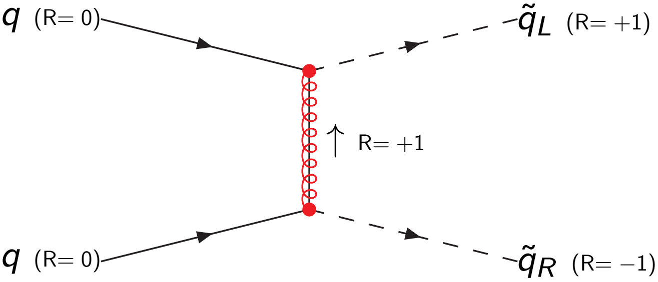
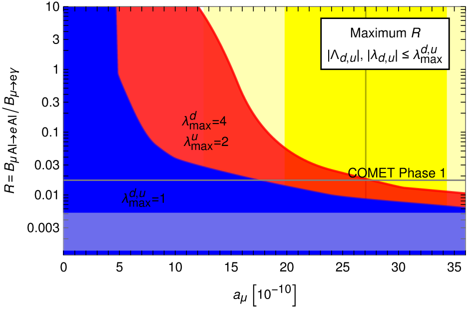


- some MSSM-processes forbidden, surviving ones suppressed
- rich EW, DM phenomenology

Question: how about a_μ in the MRSSM?
$\rightsquigarrow$ very different to MSSM $\rightsquigarrow$ interesting connection to LFV

(Non-)correlation with lepton flavour violation

- a_μ and $\mu \to e\gamma$ always correlated , $\mu \to e$ only if dipole-dominance
- MRSSM: only for $\Lambda_i \gg g$ (problematic), otherwise not!



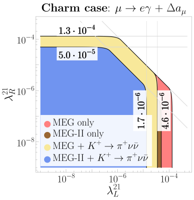
$$\frac{\mu \to e\gamma}{\mu \to e} \ \text{vs.}\ \ a_\mu$$

[Kotlarski,DS,Stöckinger-Kim'19]

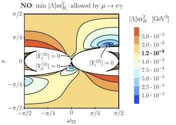
If a_μ large $\Rightarrow$ strict correlation $\overset{\text{MEG-result}}{\Rightarrow}$ $\mu \to e$ very small
If $\mu \to e$ observed $\Rightarrow$ a_μ must be small in MRSSM

Conclusions

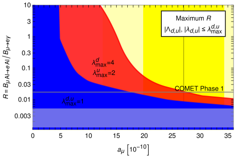
- FlexibleSUSY
  - precise BSM code which now includes CLFV, tested



- leptoquarks
  - large $\Delta a_\mu \Rightarrow$ strongly non-universal couplings



- neutrino mass via 2HDM+loops: GNM
  - LFV implies specific constraints on Higgs sector



- MRSSM — unusual beautiful SUSY model
  - a_μ very small; $\mu \to e$ can be quite large.