Lepton flavour observables in the MSSM

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Outline

1. Motivation: **L**epton **F**lavour **V**iolation
2. LFV effects in leptonic Kaon decay at NA62
   - Constraints from m_e and $(g-2)_e$
   - Effects of stau mixing $\Rightarrow$ Implication for leptonic Kaon decay
3. Chirally enhanced corrections to light lepton masses
   - Bounds on A-terms
   - Interplay between a_μ, y_μ and discovery of a light $\tilde{\mu}$ at LHC
4. Conclusions

Motivation:
Lepton Flavour Violation

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- Conservation of Lepton number: accidental symmetry of the SM, conserved to all orders in perturbation theory $\boxed{\Delta L_{e,\mu,\tau} = 0, \quad \Delta L = 0}$

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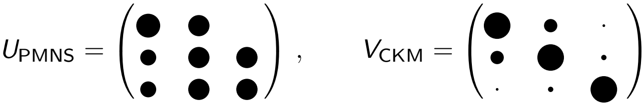
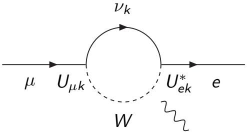
- Mixing completely different from Quark-Sector:



Clear signal for physics beyond SM

SM+ν_R: mixing of charged leptons, but unobservable:

$BR(\mu \to e\gamma) \approx \frac{3\alpha}{128\pi}\left(\frac{\Delta m_{21}^2}{M_W^2}\right)^2 \sin^2 2\theta_{12} \approx 10^{-54}$



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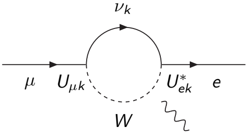
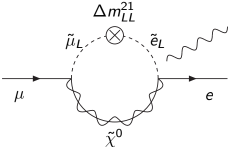


- SUSY: LFV can be induced by off-diagonal elements of the slepton mass matrix (soft breaking terms)

$$\delta^{ij}_{XY} = \frac{\Delta m^{ij}_{XY}}{\sqrt{m^2_{iX} m^2_{jY}}}, \quad X, Y = L, R, \quad i, j = e, \mu, \tau$$

Contraints from $\ell_j \to \ell_i \gamma$ (mainly δ^{ij}_{LL}, δ^{ij}_{LR})

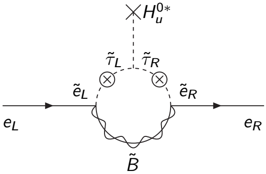


Lepton flavour violating effects
in leptonic Kaon decay?
Constraints from m_e and $(g-2)_e$

LFV corrections to y_e: Contraints from a_e and m_e

tan β-enhanced corrections: $y_{d,\ell} = \frac{m_{d,\ell}}{v_d(1+\epsilon \tan\beta)}$, [Hall, Rattazzi, Sarid, 94]

- Inclusion of LFV: $y_e = \frac{m_e + \Sigma_e^{FV}}{v_d(1+\epsilon_e \tan\beta)}$
- $\Sigma_e^{FV} \propto \frac{\alpha_1}{4\pi} \frac{m_\tau \tan\beta}{1+\epsilon_\tau \tan\beta} \delta_{LL}^{13} \delta_{RR}^{13} \Rightarrow \delta y_e = y_e \frac{\delta m_e}{m_e} \propto \frac{m_\tau}{m_e}$



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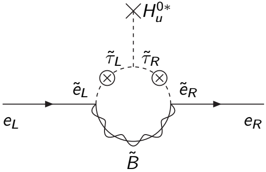

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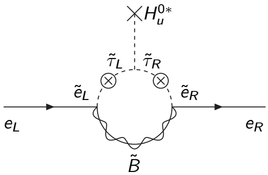

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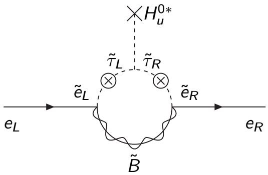

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  - $a_e^{SUSY} \propto \alpha_e \frac{m_e^2}{M_{SUSY}^2} \tan\beta \rightarrow$ negligible small. But with double LFV pick up term $\propto m_\tau \rightarrow$ comparable to weak or hadronic contributions

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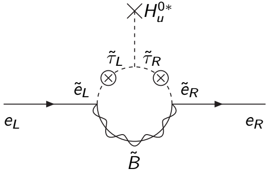

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  - most stringent bound: $\left|\delta_{LL}^{13}\delta_{RR}^{13}\right| < 0.1$.
  - since a_e decouples, bounds very loose for $M_{SUSY} \gtrsim 500$ GeV.

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  - precise SM prediction [Cirigliano, Rosell, 07]:
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Experiment	R_K [10^{-5}]	error $\delta R_K / R_K$
PDG 2006	2.45 ± 0.11	4.5%
NA48/2 '03	$2.416 \pm 0.043 \pm 0.024$	2.8%
NA48/2 '04	$2.455 \pm 0.045 \pm 0.041$	3.5%
KLOE	$2.55 \pm 0.05 \pm 0.05$	3.9%
Kaon 2007	2.457 ± 0.032	1.3%
KLOE '09	$2.493 \pm 0.025 \pm 0.019$	2.2%
NA62 '09	2.486 ± 0.013	0.5%

Probing LFV SUSY effects in NA62 experiment

- In MSSM: additional charged-Higgs contribution to $K \to \ell\nu$:
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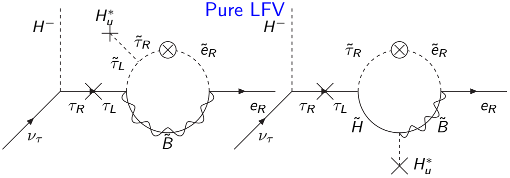
    - ⋆ But with constraints from a_e and m_e not measurable [J.G., U. Nierste, in prep. 10]
    - ⋆ model independent analysis within a THDM-II: $\delta y_e = y_e \frac{\delta m_e}{m_e} \approx y_e \frac{\Sigma_e^{FV}}{m_e}$

$$\Delta r^{\mu-e}_{\text{min,LFC}} = -4 \frac{m_K^2 \tan^2\beta}{M_H^2(1+\epsilon_s \tan\beta)}$$

For $\tan\beta = 50$, $\epsilon_s \tan\beta = 0.3$ and charged-Higgs mass $M_H = 300$ GeV:
$\Delta r^{\mu-e}_{\text{min,LFC}} = -5 \cdot 10^{-3}$ $\to$ not measurable

    - ⋆ measurement $\Delta r^{\mu-e} < \Delta r^{\mu-e}_{\text{min,LFC}}$ needs more exotic NP explanation than charged-Higgs exchange

LFV contributions to R_K



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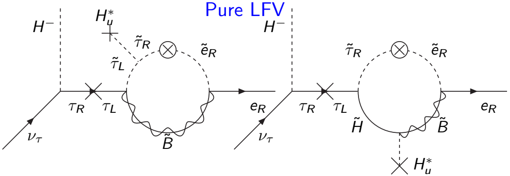

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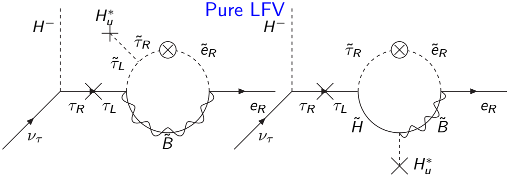

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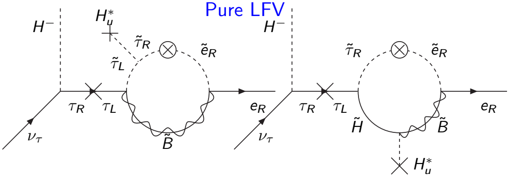
- $\Delta r_{\mathrm{LFV}}^{\mu-e} = \frac{m_K^4 \tan^4\beta}{M_H^4 (1+\epsilon_e \tan\beta)^2 (1+\epsilon_\tau \tan\beta)^2} \frac{m_\tau^2}{m_e^2} \left[\frac{\Sigma_{\tau_L - e_R}}{m_\tau}\right]^2$

LFV contributions to R_K



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- scenario: input lightest stau $m_{\tilde{\tau}_\ell} = 120$ GeV, 500 GeV $\leq \mu \leq$ 900 GeV $\rightarrow$ maximal effects for $\theta_\tau \approx 26°$ [J.G., U. Nierste, in prep. 10]:

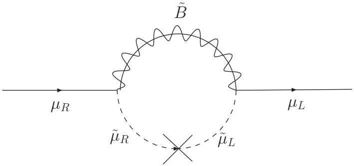
$$\Delta r^{\mu-e}_K \approx 0.006 \left(\frac{500\,\text{GeV}}{M_H}\right)^4 \left(\frac{\tan\beta}{50}\right)^6 \left(\frac{\delta^{13}_{RR}}{0.5}\right)^2 \left(\frac{\mu}{800\,\text{GeV}}\right)^2$$

- maximal LFV effects in $\Delta r^{\mu-e}_K$ ($\theta_\tau \neq 0 \neq \delta^{13}_{RR}$, large μ, light $\tilde{\tau}$) can reach future NA62 sensitivity of 0.2%

Chirally enhanced corrections
to light lepton masses
and interplay between a_μ and y_μ

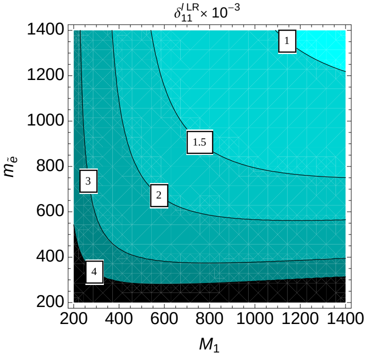
Chiral corrections to light lepton masses: LO

- possible to generate light fermion masses radiatively via *A*-terms in $\Sigma^{\tilde{\chi},\tilde{g}}_{f_L - f_R}$ [Wyler, Nilles, 82; Banks 88; Borzumati, Farrar, Polonsky, Thomas, 99; Ferrandis, Haba, 04; Crivellin, Nierste, 09]



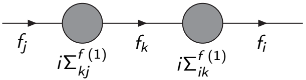
- Upper bound of fine tuning argument $|\Sigma^{\tilde{\chi},\tilde{g}}_{f_L - f_R}| \leq m_f$ corresponds to radiative mass generation [A. Crivellin, J.G, 09]

$$|\delta^{\ell\,11}_{LR}| \lesssim 0.0025 \left(\frac{500\text{ GeV}}{M_{\text{SUSY}}}\right),$$
$$|\delta^{\ell\,22}_{LR}| \lesssim 0.5 \left(\frac{500\text{ GeV}}{M_{\text{SUSY}}}\right).$$



Chirally enhanced corrections to light lepton masses: NLO

- A-terms with generic flavour structure $\Rightarrow$ also two-loop corrections can contribute: constraints $\delta^{ik}_{LR}\delta^{ki}_{LR}$ (latter unconstraint for $k > i$)



$$\left|\delta^{\ell\,13}_{LR}\delta^{\ell\,31}_{LR}\right| \lesssim \frac{64\pi^2 m_e m_\tau}{(\alpha_1 M_{\mathbf{SUSY}})^2} \approx 0.021 \left(\frac{500\text{ GeV}}{M_{\mathbf{SUSY}}}\right)^2$$

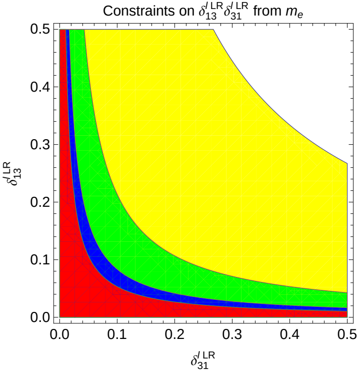


Figure: Naturalness bound $M_{\mathrm{SUSY}} = 200$ GeV (yellow), 500 GeV (green), 800 GeV (blue), 1000 GeV (red)

Correlating a_μ and y_μ

- 3.2σ discrepancy: $a_\mu^{\rm exp} - a_\mu^{\rm SM} = (25.5 \pm 8.0) \times 10^{-10}$ [Jegerlehner, Nyffeler, 09; Passera, Marciano, Sirlin, 01; Prades 10; Teubner, Hagiwara, Liao, Martin, Nomura, 01]

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- interplay between soft y_μ generated radiatively with A-terms and a_μ:

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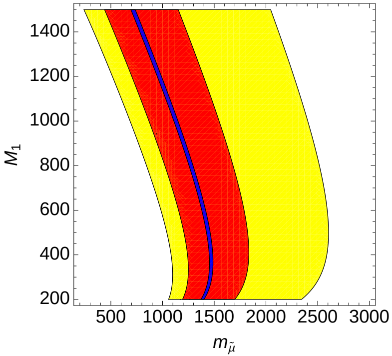

- Left: Allowed region in the M_1-$m_{\tilde{\mu}}$ plane ($m_{\tilde{\mu}}$ is the lighter smuon mass). Yellow: $a_\mu \pm 2\sigma$, red: $a_\mu \pm 1\sigma$, blue: $a_\mu \Rightarrow$ 750 GeV $\leq m_{\tilde{\mu}} \leq$ 2700 GeV
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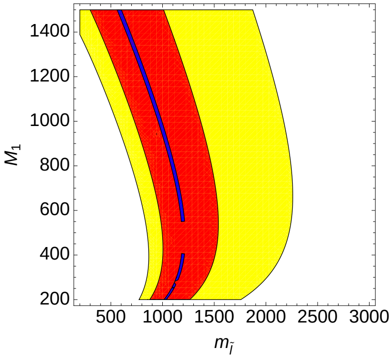

- Left: Allowed region in the M_1-$m_{\tilde\ell}$ plane ($m_{\tilde\ell}$ is the lighter slepton mass). Yellow: $a_\mu \pm 2\sigma$, red: $a_\mu \pm 1\sigma$, blue: $a_\mu \Rightarrow$ 600 GeV $\leq m_{\tilde\ell} \leq$ 2300 GeV
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Thank's for your attention