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Implications of $Br(\mu \to e\gamma)$ and Δa_μ on Muonic Lepton Flavor Violating Processes

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Motivation

- Charged lepton flavor violation decays are prohibited in the SM
- MEG recently set a tight bound on $Br(\mu \to e\gamma)$

$$Br(\mu^+ \to e^+\gamma) < 5.7 \times 10^{-13}$$

- Muon g-2 remains an unsolved puzzle (3.xσ) (since 2001)

$$\Delta a_\mu = a_\mu^{\exp} - a_\mu^{SM} = (287 \pm 63 \pm 49) \times 10^{-11}$$

- Bounds on $\mu \to e\gamma$, 3e, muon to electron conversions ($\mu\ N \to e\ N$) are constantly improved

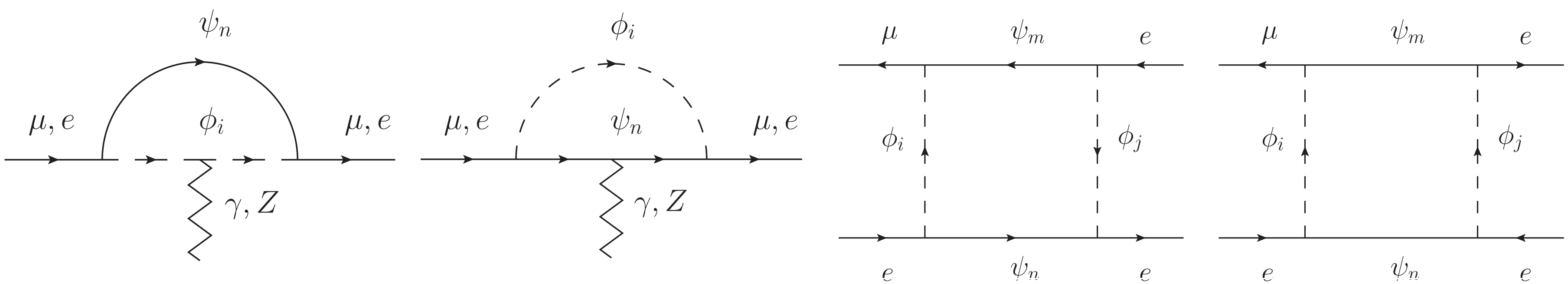
Current limits and future sensitivities

	current limit	future sensitivity
$\mathcal{B}(\mu^+ \to e^+\gamma)$	$< 5.7 \times 10^{-13}$	10^{-13}
$\mathcal{B}(\mu^+ \to e^+e^+e^-)$	$< 1.0 \times 10^{-12}$	$10^{-14} - 10^{-16}$
$\mathcal{B}(\mu^-\mathrm{Ti} \to e^-\mathrm{Ti})$	$< 4.3 \times 10^{-12}$	10^{-18}
$\mathcal{B}(\mu^-\mathrm{Au} \to e^-\mathrm{Au})$	$< 7 \times 10^{-13}$	$10^{-14} - 10^{-16}$
$\mathcal{B}(\mu^-\mathrm{Al} \to e^-\mathrm{Al})$	$\cdots$	10^{-16}

- “Ratios of current bounds” ~ *O*(1~10).
- Sensitivities will be improved by 1-6 orders of magnitudes in future

We consider…

- Muon g-2 and LFV generated by ϕ-ψ one-loop dig.s:



$\Delta a_\mu,\ \mu \to e\gamma, 3e,\ \mu N \to eN$

$\mu \to 3e$

- Use a bottom up approach:

  data $\rightarrow$ couplings, masses

- Study the correlations among these processes

Investigate Two Cases:

- Case I: Cancellations among diagrams are not effective (~order of magnitudes)

- Case II: Have some built-in cancellations, e.g. SGIM.

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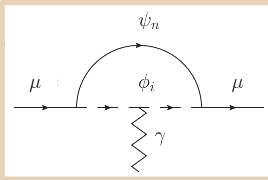
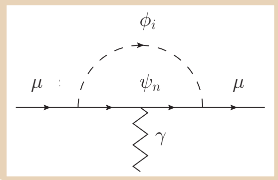
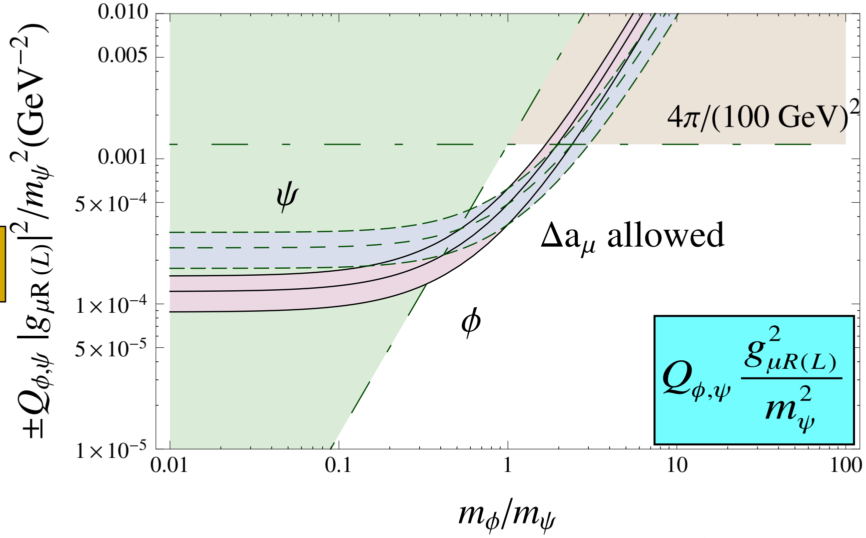
Muon g-2 (case I)

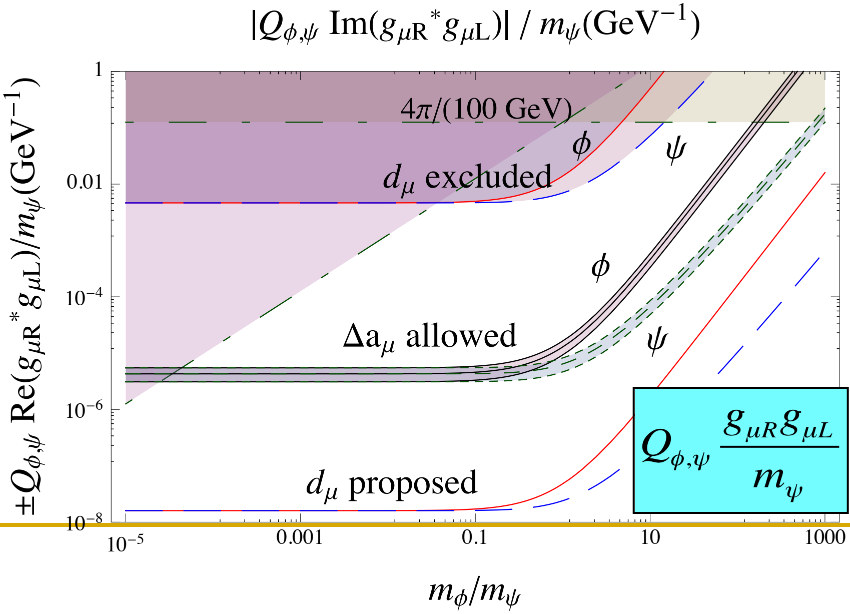




10^{-4}

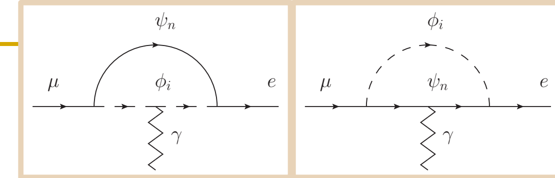


10^{-5}



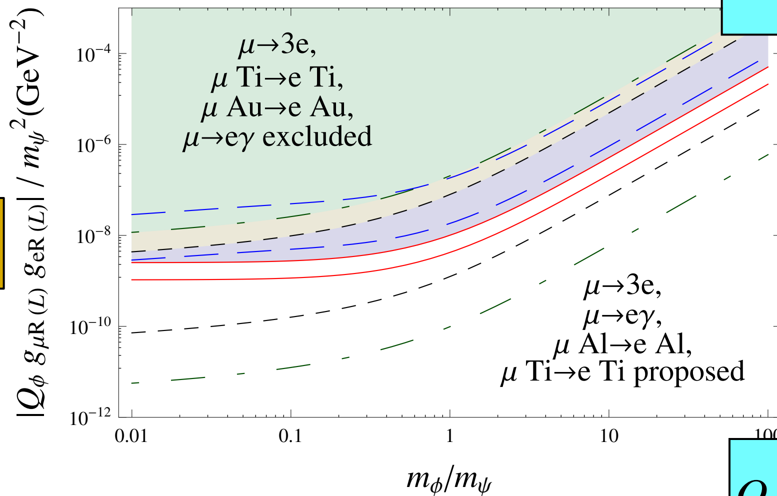
- $g_{R(L)}$: couplings of $\mu_{R(L)}$-ψ-ϕ int.
- $g_R g_R$ ($g_L g_L$) term:
  - From $g^2<4\pi$ and $m_{\psi,\phi}$ >100GeV: $m_{\psi,\phi}$<300(200)GeV (tight)
  - g~e: $m_{\psi,\phi}$=10-30GeV (disfavored)
- $g_R g_L$ term: (chiral enh.)
  - From $g^2<4\pi$ and $m_{\psi,\phi}$ >100GeV: m_ϕ<100TeV, m_ψ<3000TeV
  - g~e: m_ψ~ 20 TeV
  - More sensitive than the RR case

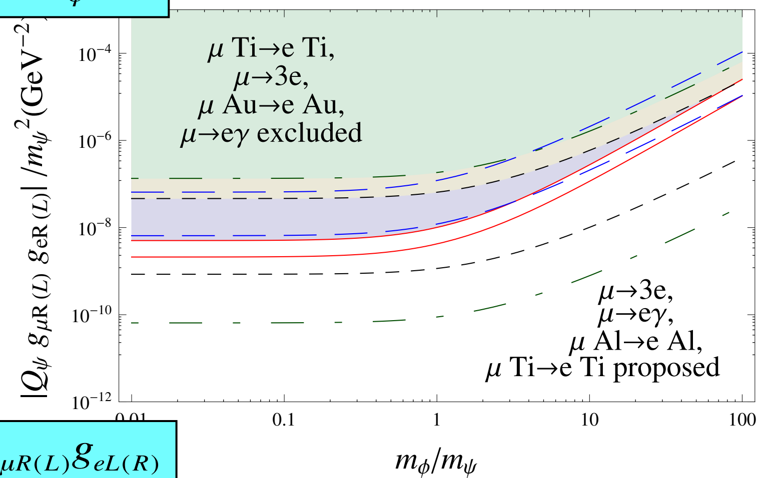
μ LFV (penguins) (case I)



$$Q_{\phi,\psi}\frac{g_{\mu R(L)}g_{eR(L)}}{m_\psi^2}$$

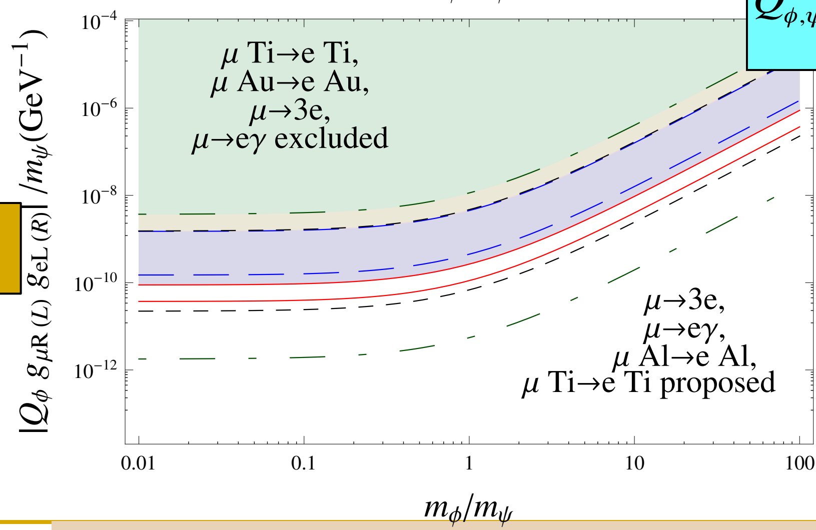
10^-8

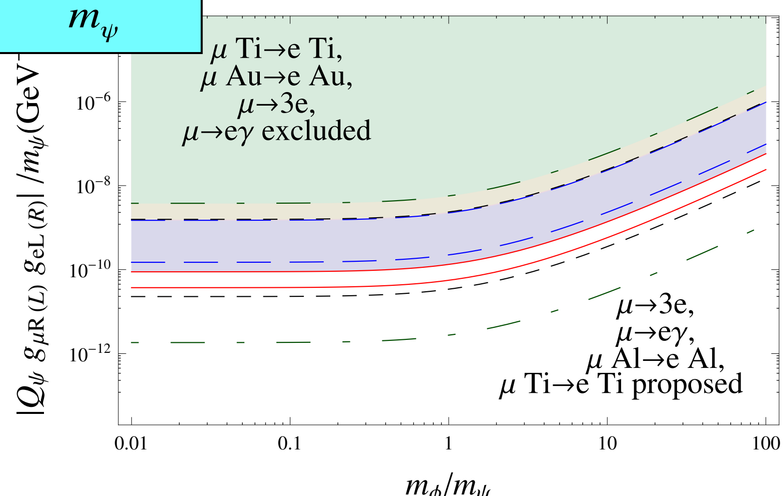




$$Q_{\phi,\psi}\frac{g_{\mu R(L)}g_{eL(R)}}{m_\psi}$$

10^-9

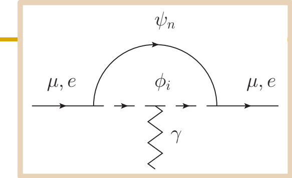


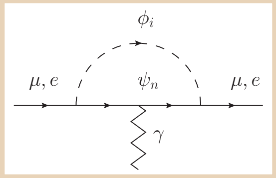


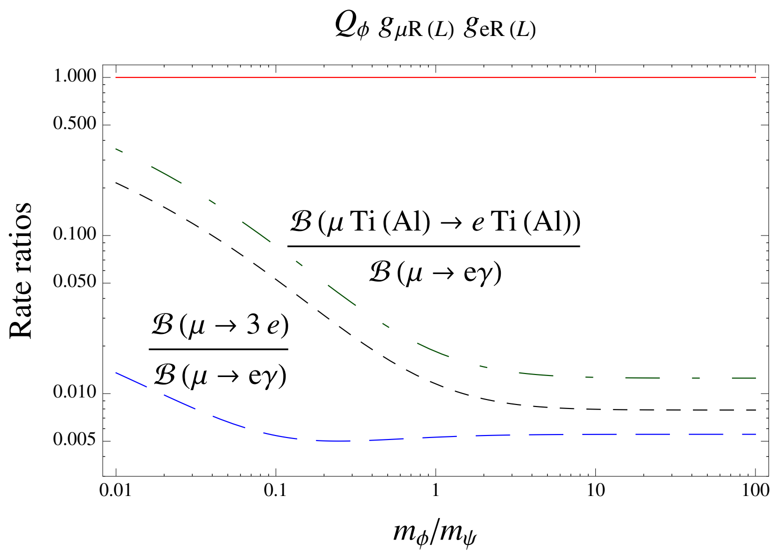
Sensitive in RL is more than 3 orders of mag. better than the RR case

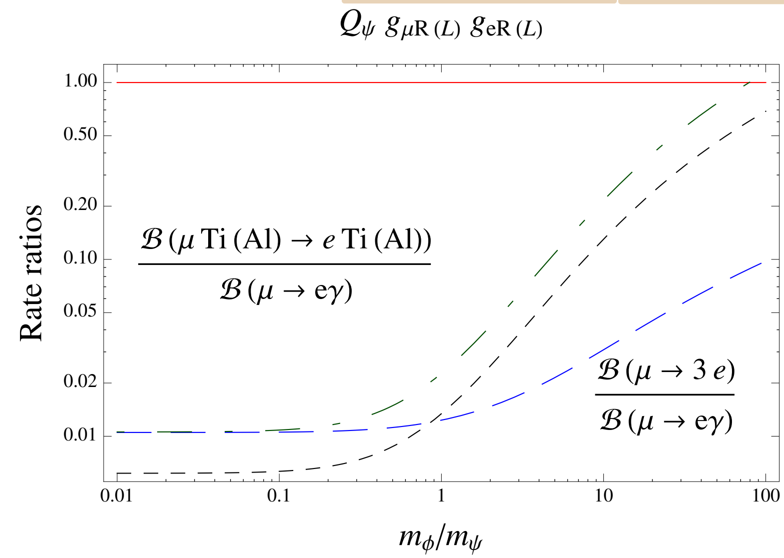
$\mu\to e\gamma$ bound is most severe

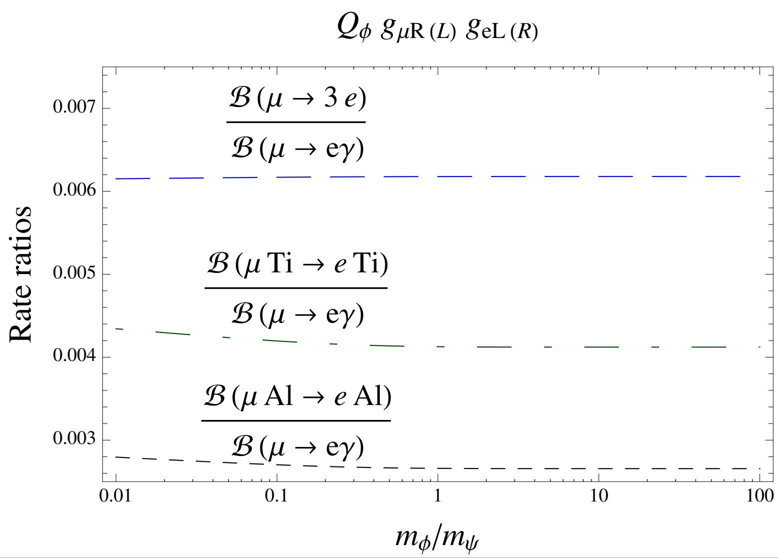
μ LFV (penguins) (case I)

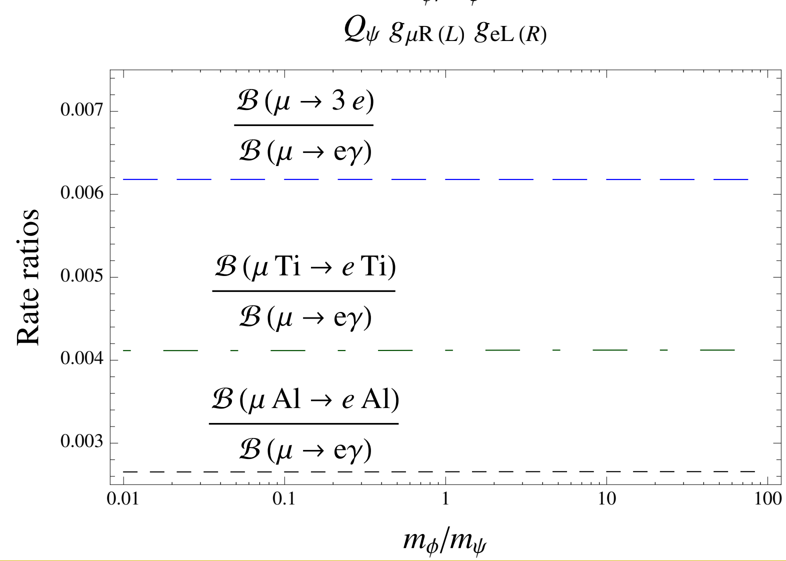








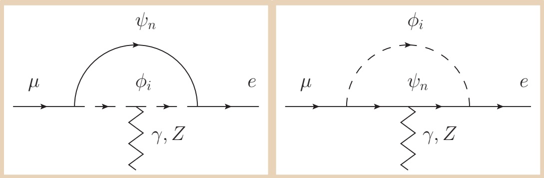




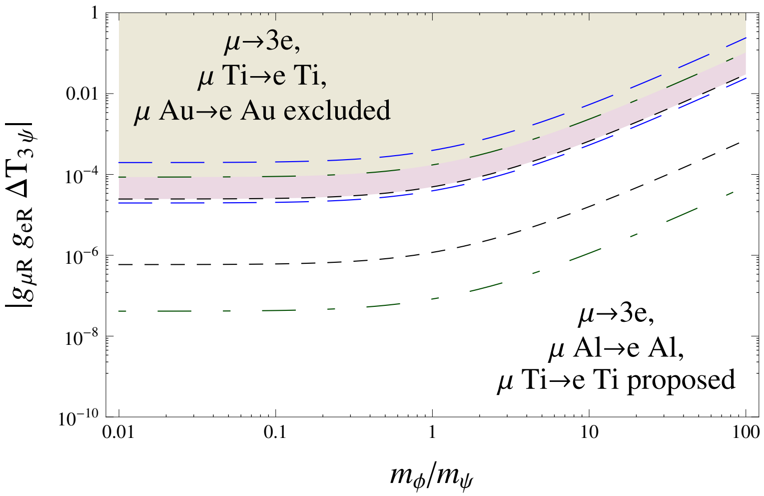
Exp. bound ratios ~ O(1~10)

$\mu \to e\gamma$ constrains other processes

μ LFV (Z-penguins) (case I)

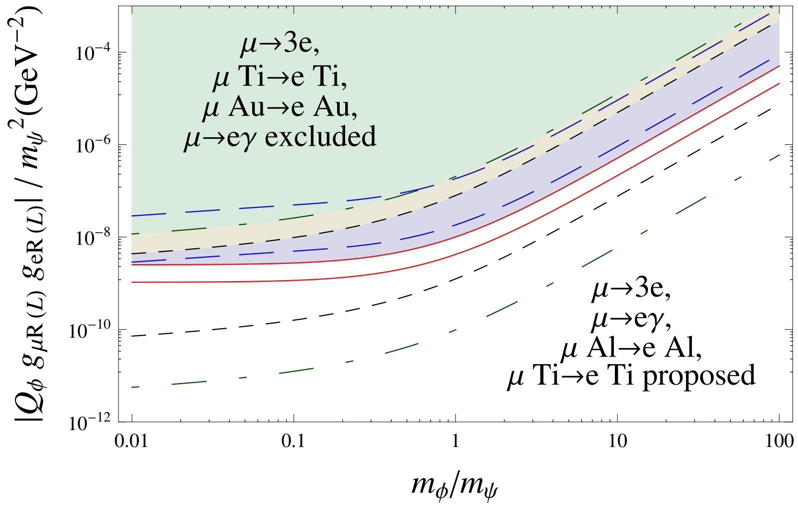


10^{-4}



Z-peg.

10^{-8}

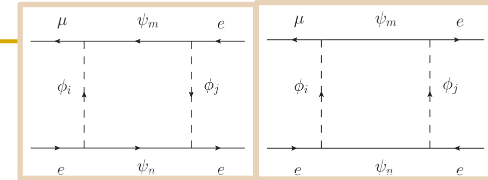


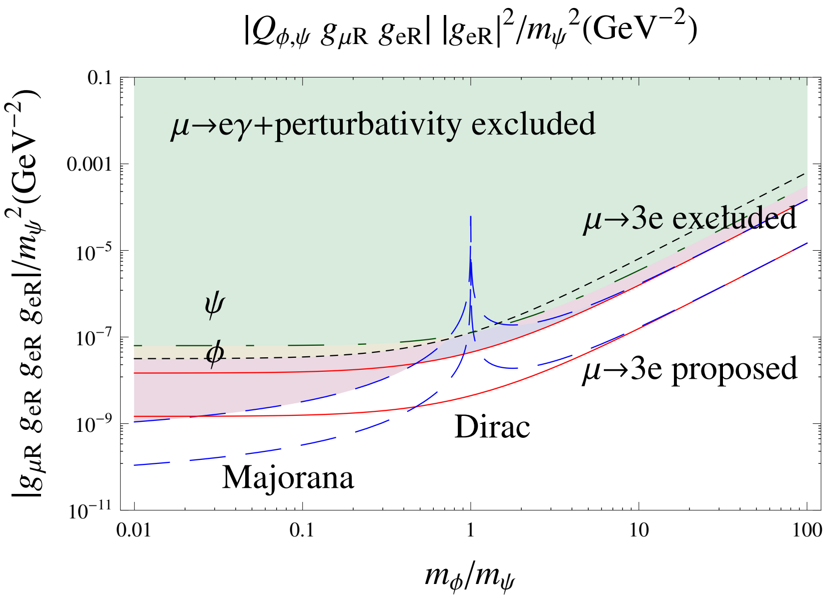
γ-peg.

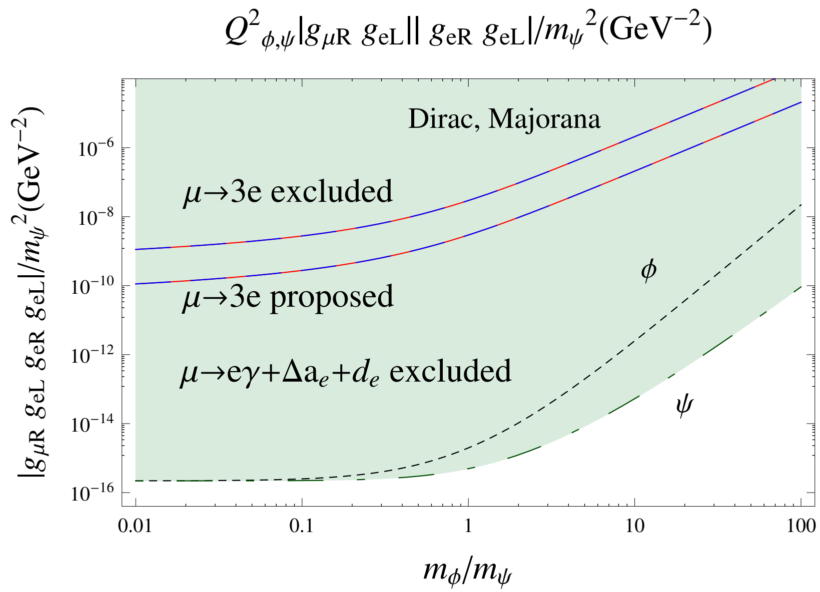
- For m_ψ=(>)O(100)GeV, Z-peng. has similar (better) sensitivity as the RR γ-peng.
- Z-peng is less sensitive than the RL γ-peng. unless m_ψ is as heavy as O(100) TeV
- Br(Z→ μ e) <$10^{-13\sim15}$ [Br_{UL}(Z→ μ e) ~10^{-6}]

$$\Delta T_{3\psi mn} \equiv V^R_{mp} T_{3\psi_R p} V^{\dagger L}_{pn} - V^L_{mp} T_{3\psi_L p} V^{\dagger R}_{pn}$$

μ LFV (boxes) (case I)

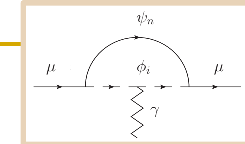


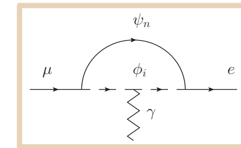


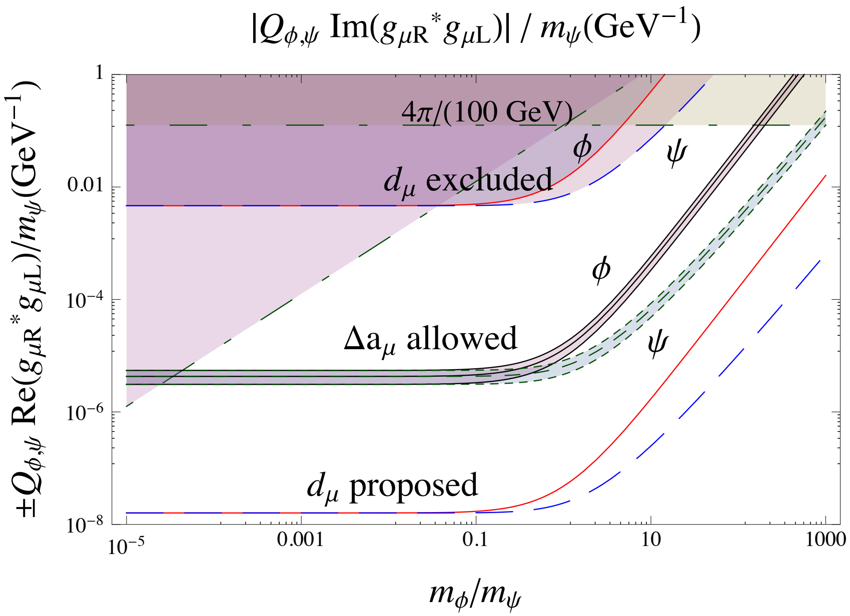


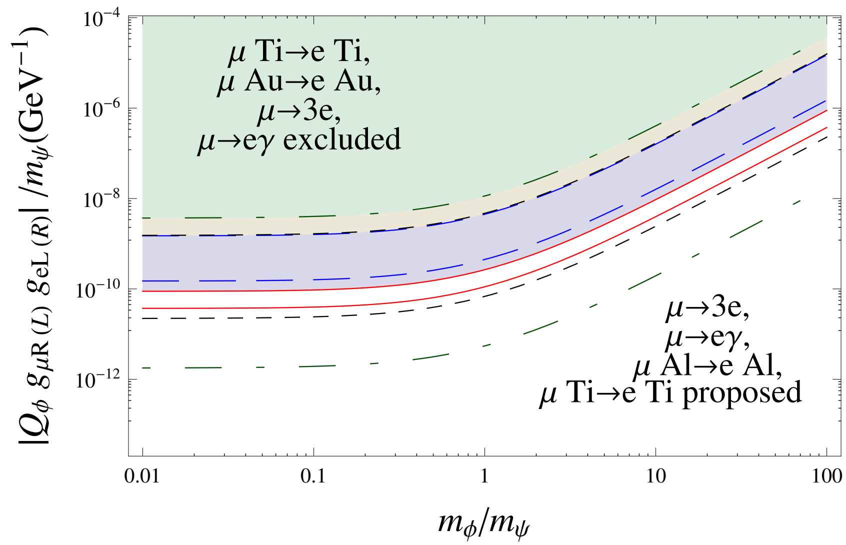
- Dirac and Majorana cases have different sensitivities
- $\mu\to e\,\gamma$+perturbativity (+Δa_μ+edm) exclude some (most) parameter space.

Comparing $Br(\mu \rightarrow e\gamma)$ and Δa_μ









$$\frac{g_{\mu R(L)} g_{eL(R)}}{g_{\mu R} g_{\mu L}} = \frac{g_{eL(R)}}{g_{\mu L(R)}} \leq 2.1 \times 10^{-5} \simeq \lambda^7$$

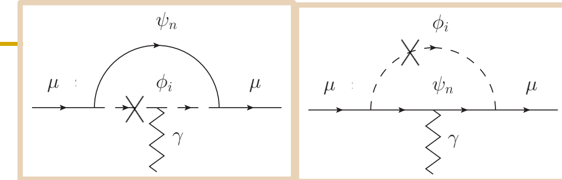
- The ratio is smaller than any known coupling ratio among 1st and 2nd generations. $\frac{g_e}{g_\mu} \approx \frac{m_e}{m_\mu} \approx \lambda^{3\sim 4}$

Investigate Two Cases:

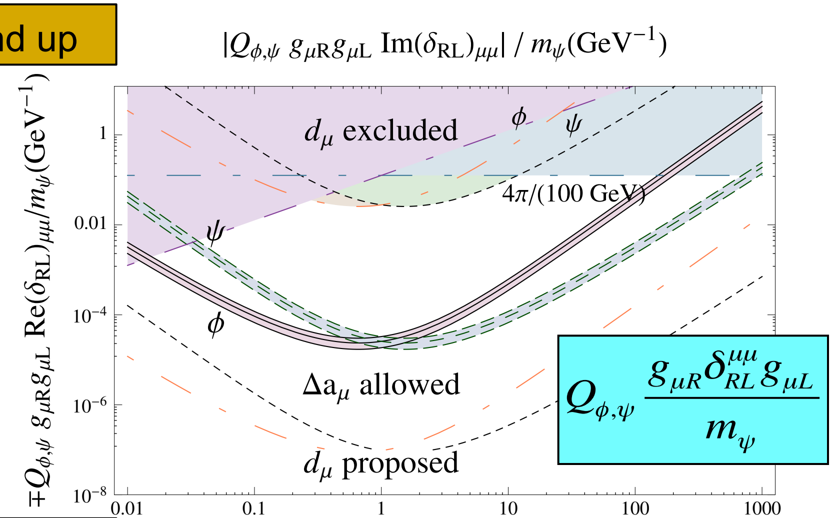
- Case I: Cancellations among diagrams are not effective (~order of magnitudes)

- ⇨ Case II: Have some built-in cancellations, e.g. SGIM.

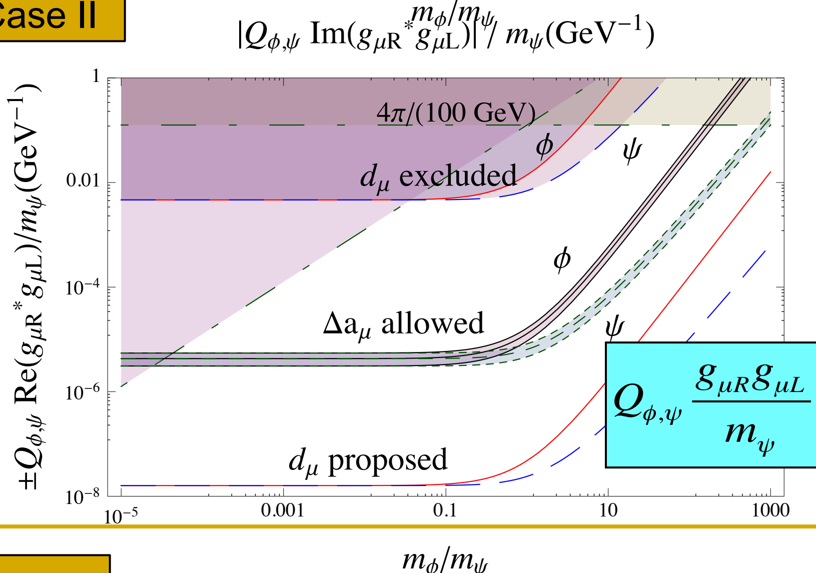
Muon g-2 (case II)



Bend up

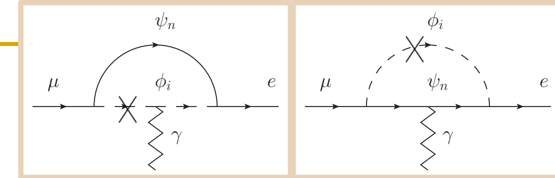


Case II

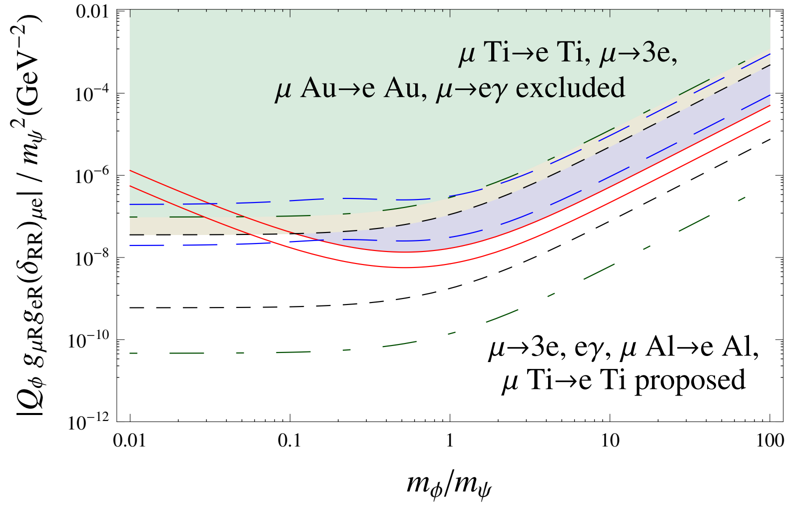


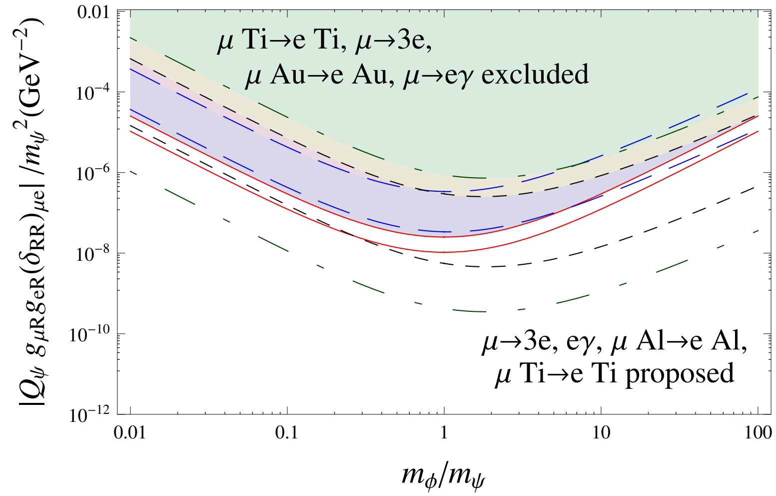
Case I

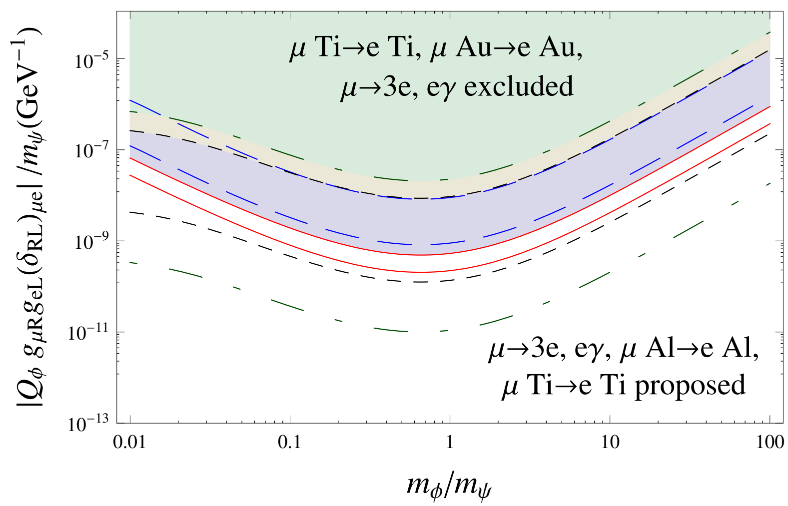
- $\delta=(\delta m^2/m^2)_\phi$: mixing angle
- $g_{R(L)}g_{R(L)}$ term same as case I
- $g_R g_L$ term: (chiral enh.)
  - Cancelation is working at the low m_ϕ/m_ψ mass ratio region
  - need larger couplings, smaller mass
  - From $g^2<4\pi$ and $m_{\psi,\phi}$ >100GeV: m_ϕ<100 TeV, m_ψ<few TeV [m_ϕ<100TeV, m_ψ<3000TeV (case I)]
  - For g~ e, δ=1, $m_\phi=m_\psi$~3 TeV [m_ψ=20TeV (case I)]

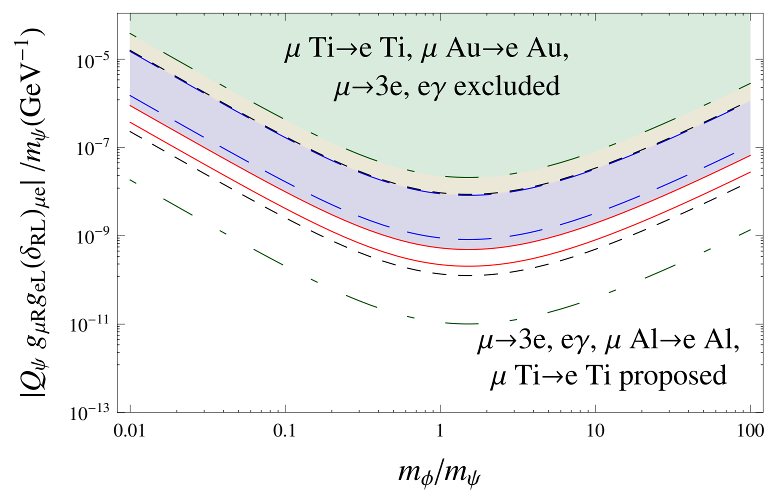


μ LFV (penguins) (case II)







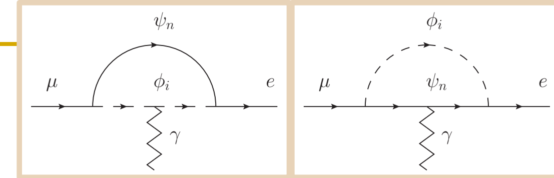


Sensitivities are relaxed

$\mu \to e\gamma$ bound is not always the most stringent one

For comparison, recall…

μ LFV (penguins) (case I)

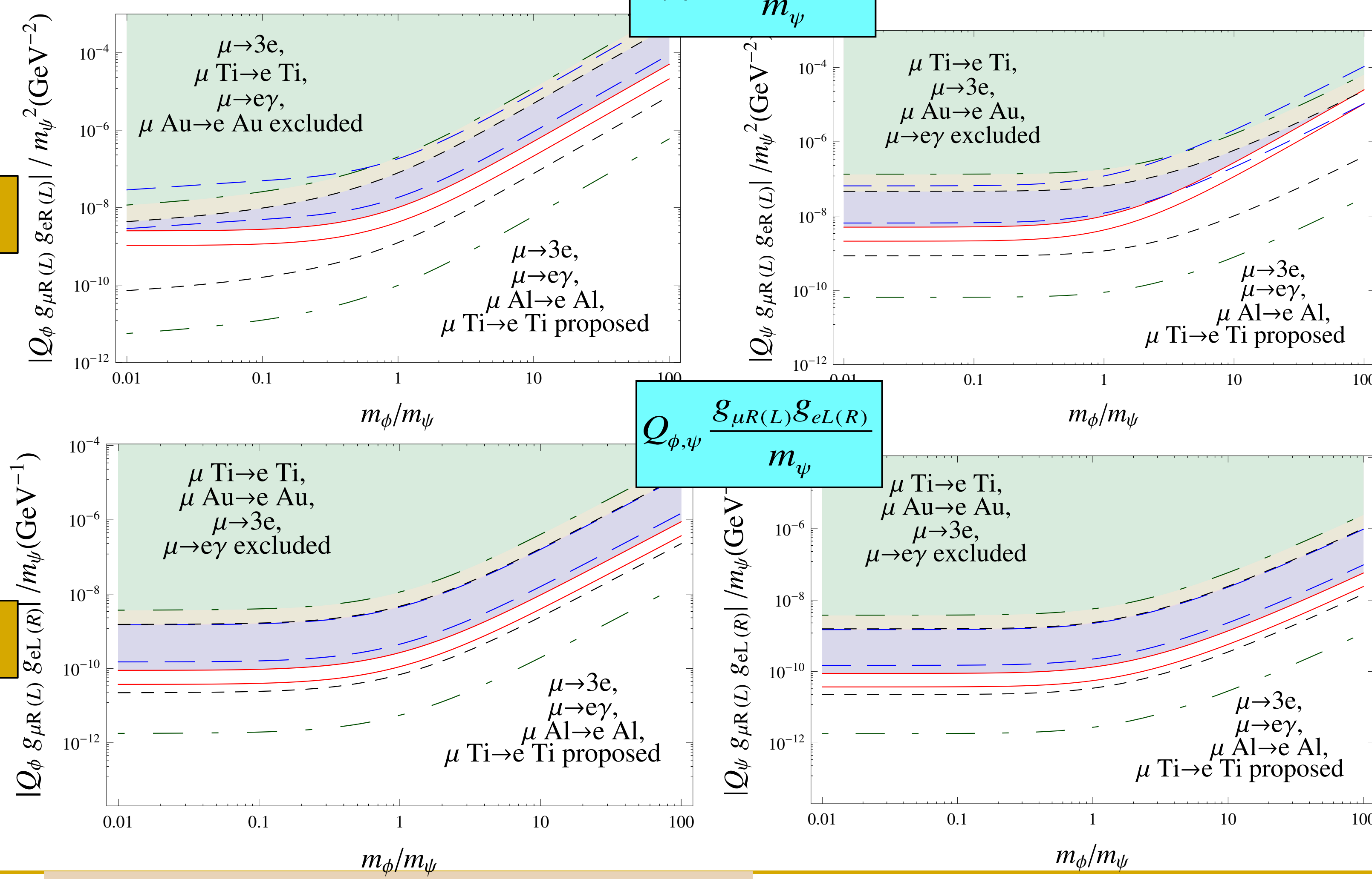


$$Q_{\phi,\psi}\frac{g_{\mu R(L)}g_{eR(L)}}{m_\psi^2}$$

10^{-8}

$$Q_{\phi,\psi}\frac{g_{\mu R(L)}g_{eL(R)}}{m_\psi}$$

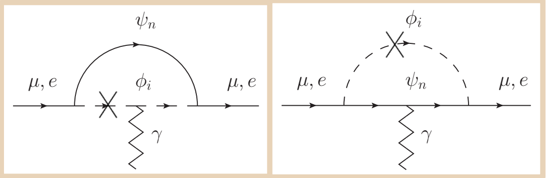
10^{-9}

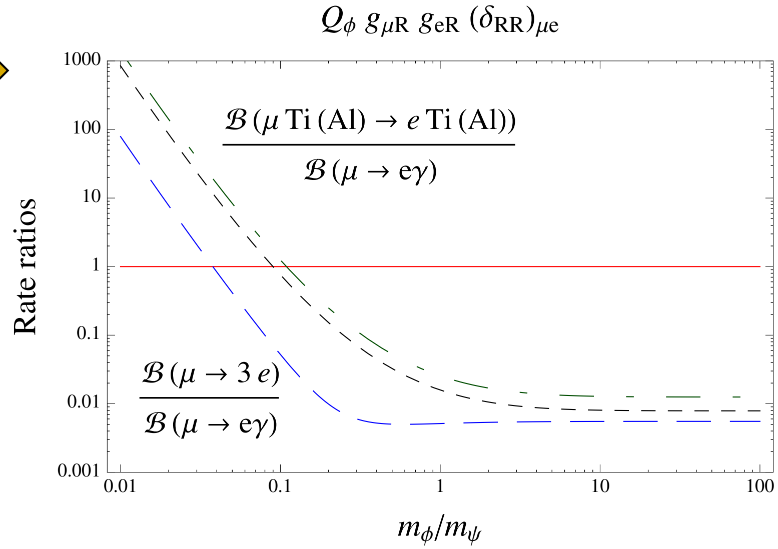


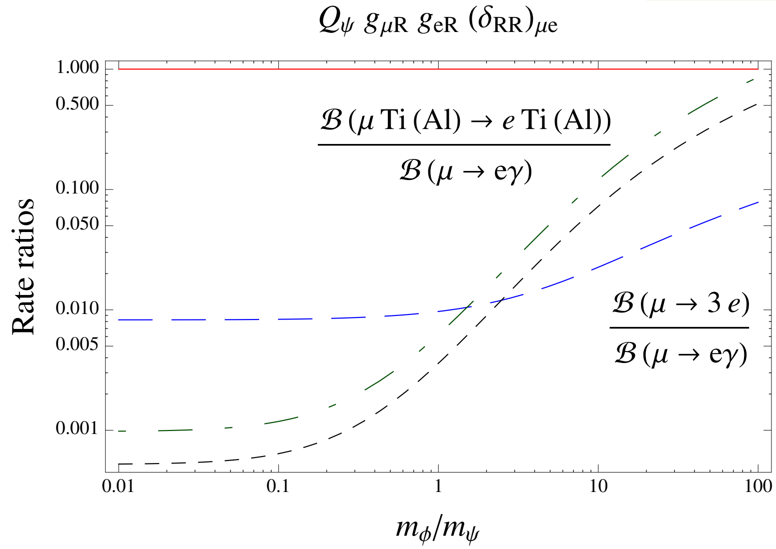
Sensitive in RL is more than 3 orders of mag. better than the RR case

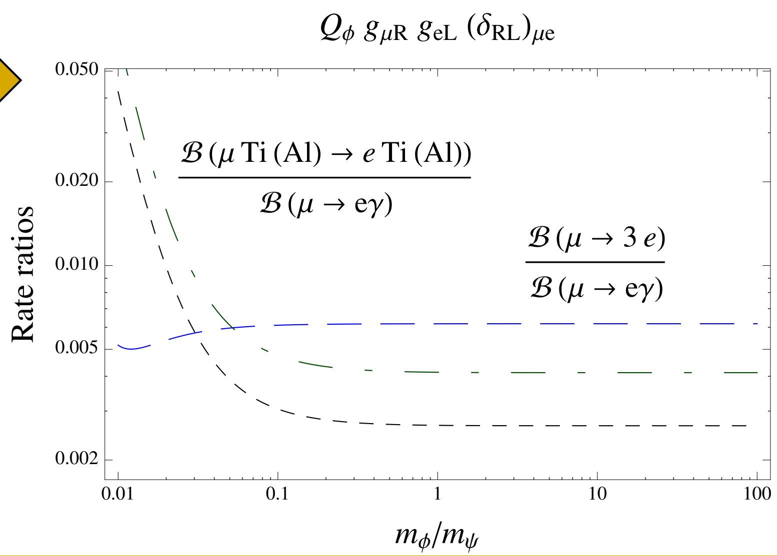
$\mu \to e\gamma$ bound is most severe

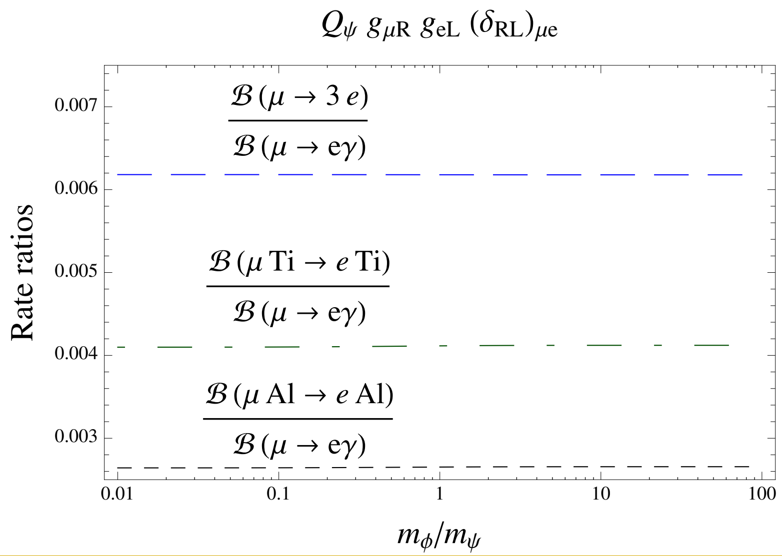
μ LFV (penguins) (case II)







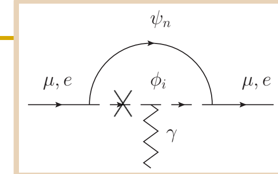


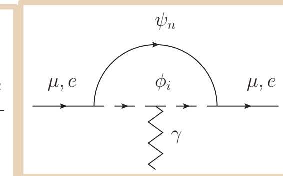


$\mu N \to eN$ enhanced relatively (B~10^{-14})

$\mu \to e\gamma$ bound is not always the most stringent one

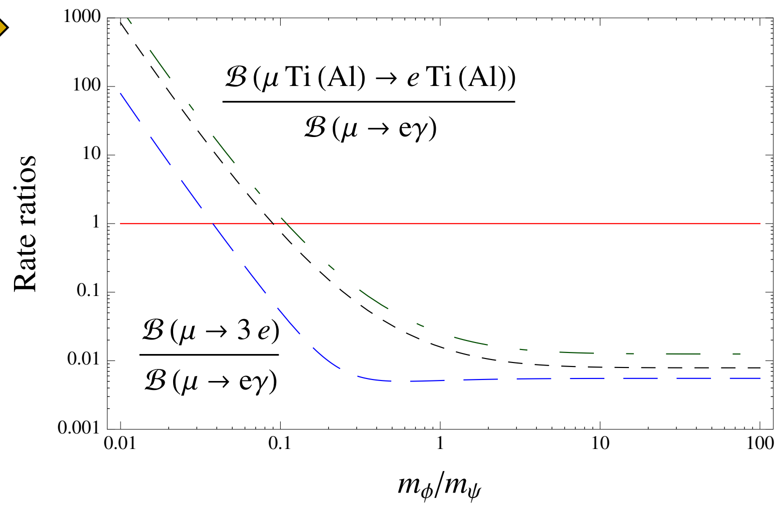
μ LFV (penguins)(comparing)



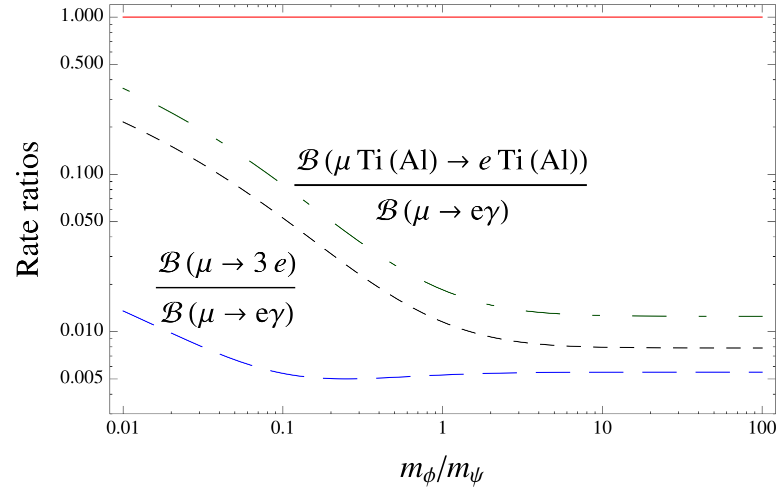


Case II | **Case I**

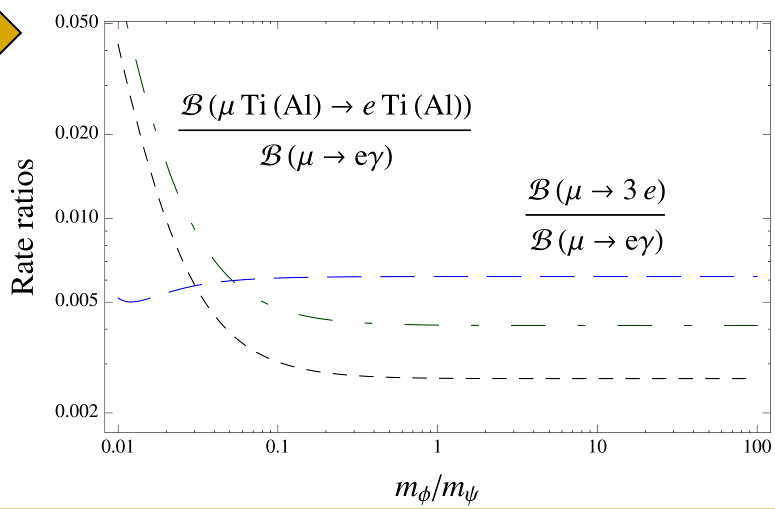
$Q_\phi\, g_{\mu R}\, g_{eR}\, (\delta_{RR})_{\mu e}$



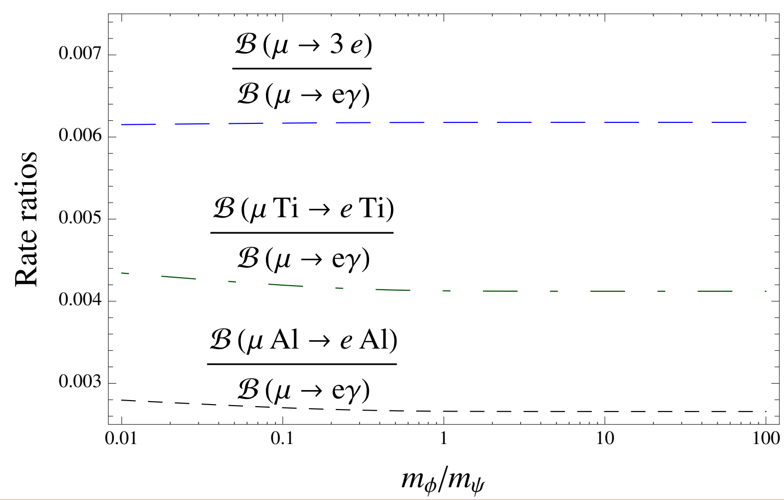
$Q_\phi\, g_{\mu R\,(L)}\, g_{eR\,(L)}$



$Q_\phi\, g_{\mu R}\, g_{eL}\, (\delta_{RL})_{\mu e}$

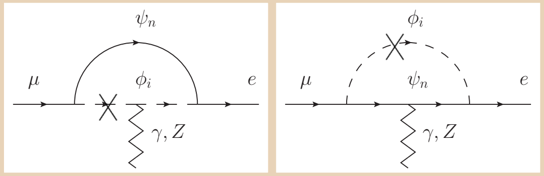


$Q_\phi\, g_{\mu R\,(L)}\, g_{eL\,(R)}$

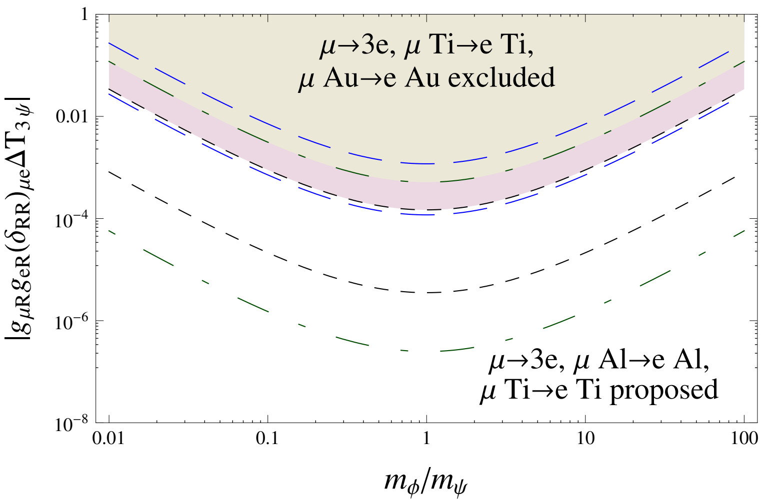


$\mu N \to eN$ is enhanced relatively in case II

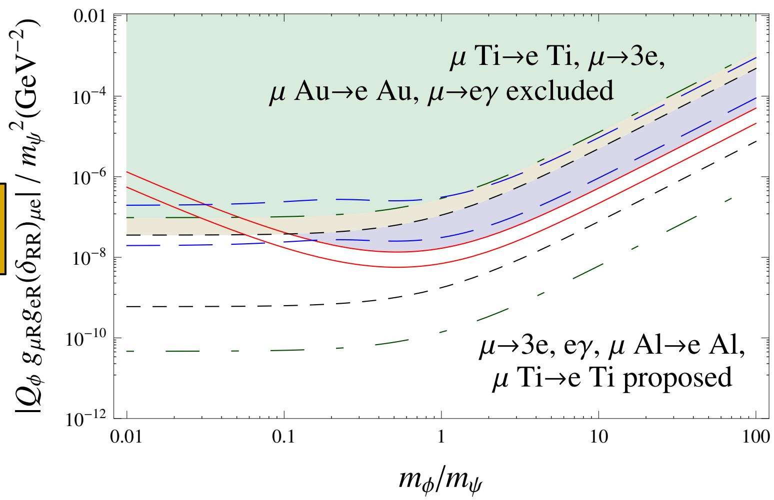
μ LFV (Z-penguins) (case II)



10^-2



10^-7

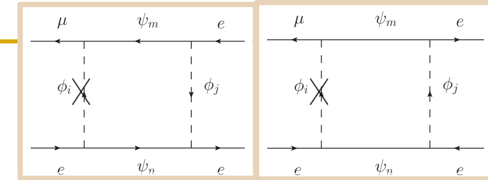


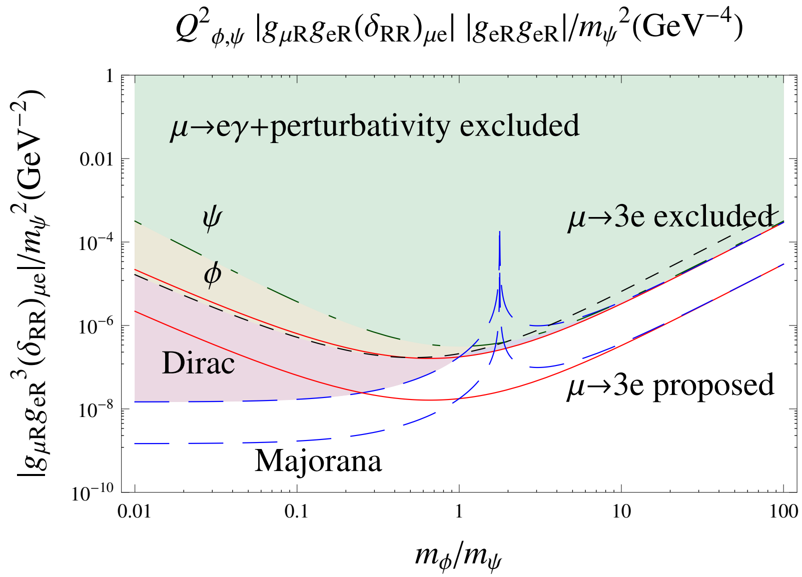
Z-peg.

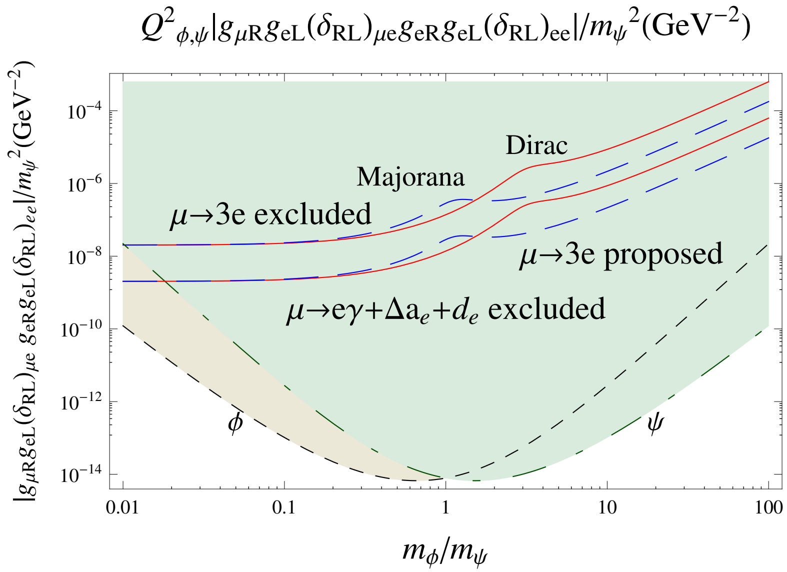
γ-peg.

- Z-peng. sensitivity is relaxed in the low mass ratio region, for m_ψ= (>)O(300~1000)GeV, Z-peng. has similar (better) sensitivity as the RR γ-peng.
- Z-peng. is less sensitive than the RL γ-peng. unless m_ψ is as heavy as $O(10^3)$ TeV (not supported by g-2 [m_ψ<few TeV])
- **Z-peng. is subdominant in this case.**
- Br(Z→ μ e) <$10^{-13\sim15}$ [Br_{UL}(Z→ μ e) ~10^{-6}]

μ LFV (boxes) (case II)







- Dirac and Majorana cases have different sensitivities
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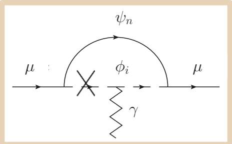
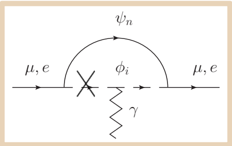
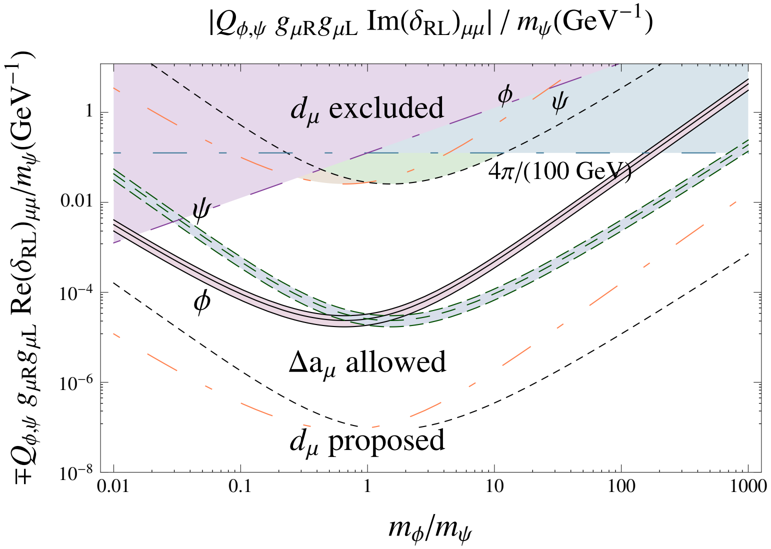
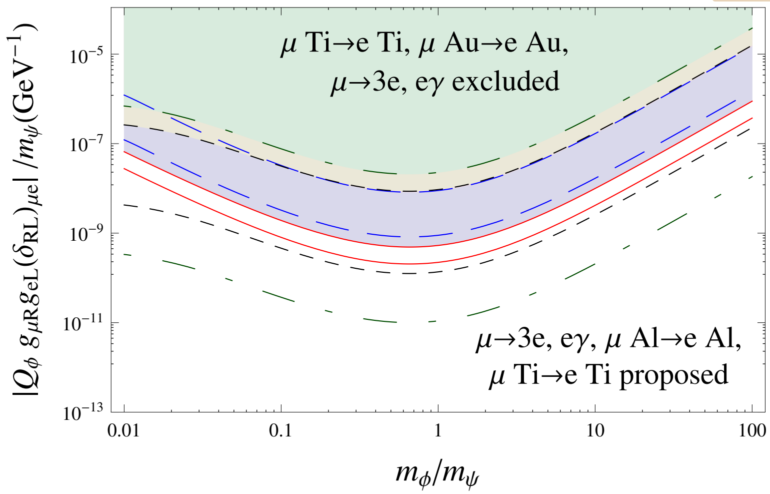
Comparing $Br(\mu\to e\gamma)$ and Δa_μ









$$\frac{g_{\mu R(L)}g_{eL(R)}\mathrm{Re}[(\delta_{RL(LR)})_{\mu e}]}{g_{\mu R}g_{\mu L}\mathrm{Re}[(\delta_{RL})_{\mu\mu}]}=\frac{g_{eL(R)}}{g_{\mu L(R)}}\frac{\mathrm{Re}[(\delta_{RL(LR)})_{\mu e}]}{\mathrm{Re}[(\delta_{RL})_{\mu\mu}]}\le 2.1\times 10^{-5}\simeq\lambda^7$$

- Can be satisfied with

$$\frac{g_e}{g_\mu}\approx\frac{m_e}{m_\mu}\approx\lambda^{3\sim 4}\qquad\frac{\mathrm{Re}[(\delta_{RL(RL)})_{\mu e}]}{\mathrm{Re}[(\delta_{RL})_{\mu\mu}]}\le\lambda^{3\sim 4}$$

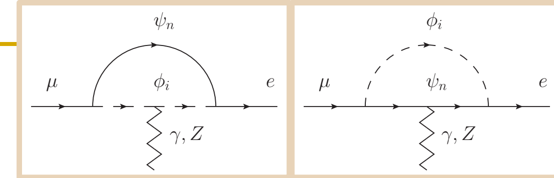
Conclusion

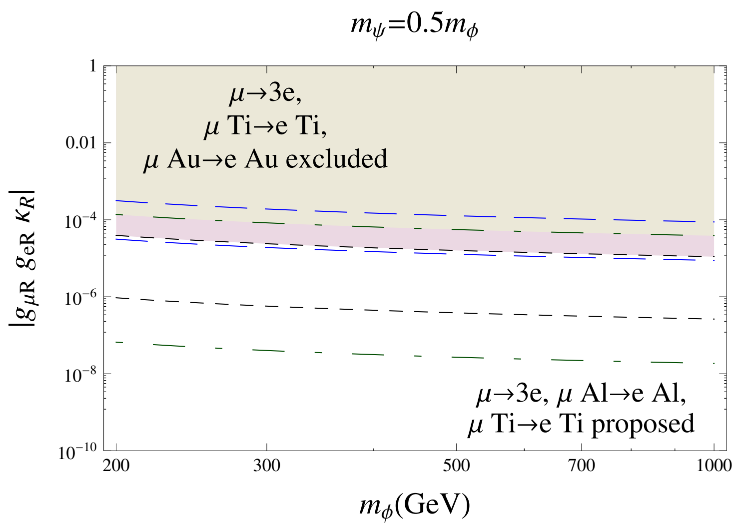
- Consider ψ-ϕ loop-induced LFV muon decays.
- Bounds are translated to constraints on parameters (couplings and masses)
- Muon g-2 favors non-chiral interaction
- Z-penguin may play some role

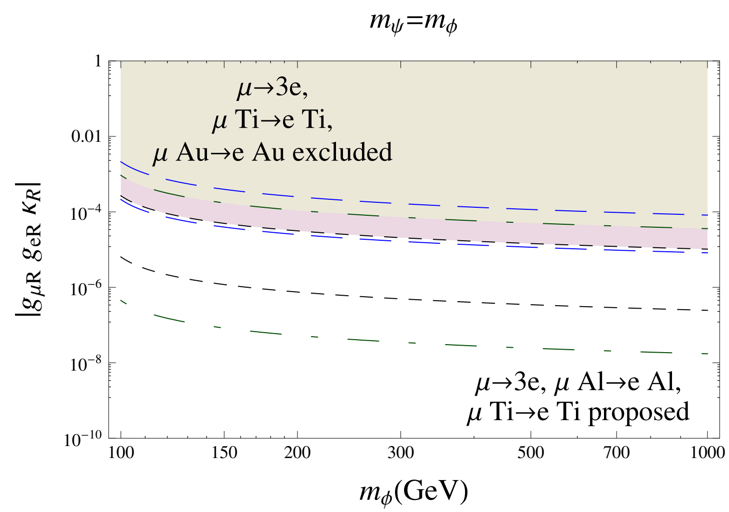
  Box diagram contributions are highly constrained from other's
- Comparing different cases, we found that:
  - Case I (no cancellation):
    - Need fine-tune to satisfy $Br(\mu \to e\gamma)$ and Δa_μ
    - $\mu \to 3e$, $\mu N \to e\, N$ bounded by $\mu \to e\,\gamma$ (2~3 orders below expt.)
  - Case II (built-in cancellation):
    - Mixing angles soften the fine-tune in $Br(\mu \to e\gamma)$ and Δa_μ
    - $\mu \to 3e$ remains suppressed, but $\mu N \to e\, N$ is enhanced

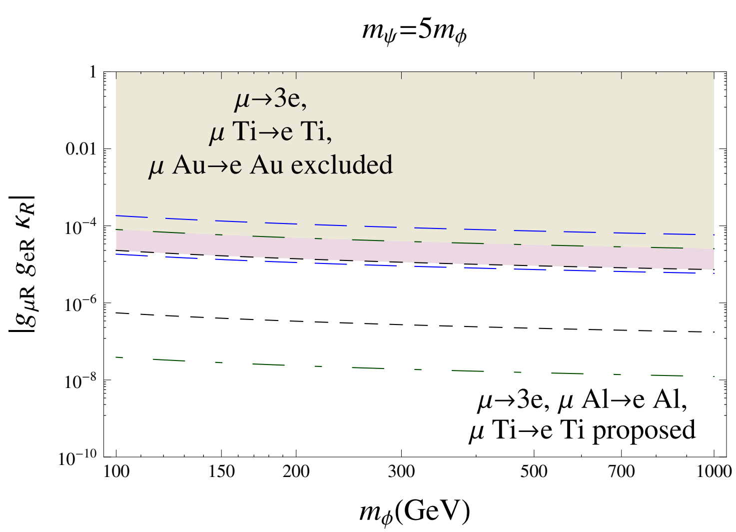
Back up

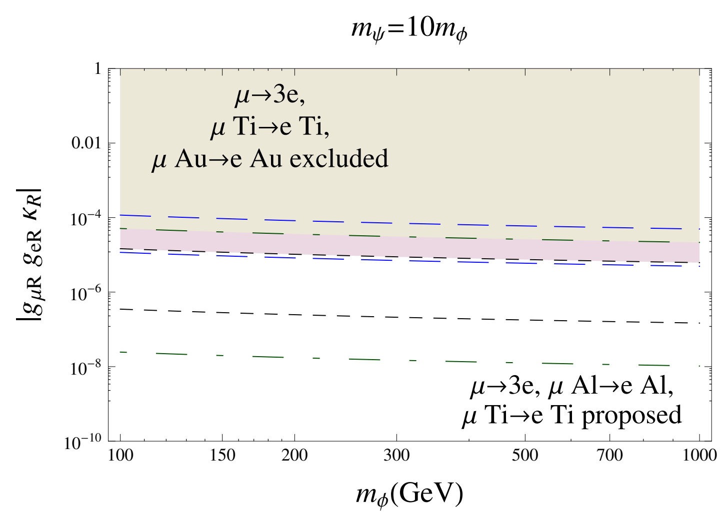
μ LFV (Z-penguins)











$$\kappa_{L(R)ijmn} \equiv \sin 2\theta_W (g^Z_{l_{L(R)}} \delta_{ij}\delta_{mn} - g^Z_{\psi_{R(L)}\,mn}\delta_{ij} - g^Z_{\phi\,ij}\delta_{mn})/e,$$