Muon flavor violation and EDM in light of muon g-2

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I. Introduction

- Recent confirmation of muon $g-2$ anomaly by Fermilab may harbinger new era in μ/τ physics.
- Measured $a_\mu \equiv (g-2)/2$ larger than SM value by $\sim 4\sigma$:

$$\Delta a_\mu = a_\mu^{\rm Exp} - a_\mu^{\rm SM} = (251 \pm 59) \times 10^{-11}$$

- *General* two-Higgs-doublet model (g2HDM) can explain via known one-loop exchange of sub-TeV exotic scalars H and A.

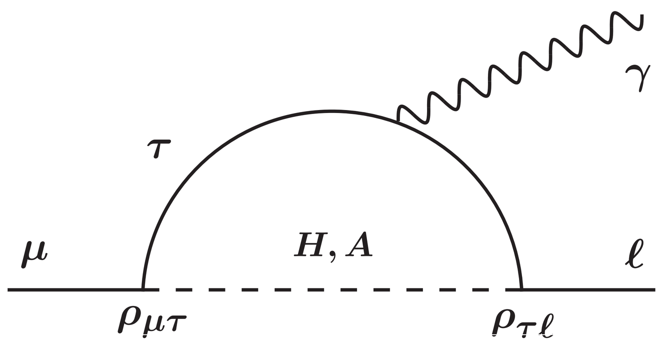


Diagram for muon g-2 ($\ell = \mu$).

- Three main ingredients:
  - ✔ $m_H \neq m_A$
  - ✔ $\rho_{\tau\mu} \approx \rho_{\tau\mu} \simeq 20\lambda_\tau^{\ddagger}$, where $\lambda_\tau \simeq 0.01$ in SM.
  - ✔ Near alignment limit i.e., mixing $c_\gamma \cong 0$ between h-H.

⟹ Same mechanism predicts μ and τ flavor violation; Muon electric dipole moment measurable at PSI.

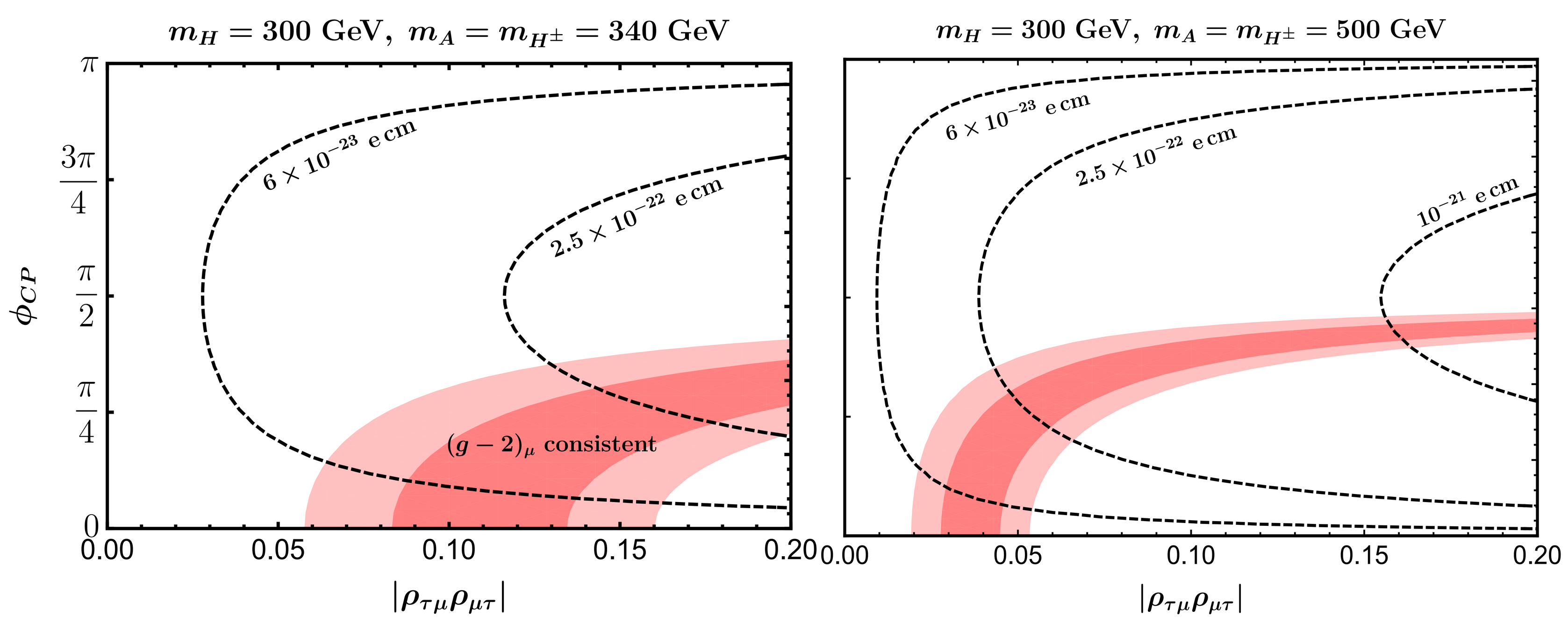
‡CMS $pp \to H, A \to \tau\mu$ more stringent than Belle $\tau \to \mu\gamma$! [WSH, Jain, Kao, GK and Modak, PRD 104 (2021) 075036]

II. Muon electric dipole moment

- (small) CP violation in SM rooted in Yukawa.
- In g2HDM, no *ad hoc* Z_2 symmetry; Yukawa matrix of exotic doublet Φ' ("SM doublet" Φ gives SSB) cannot be diagonalized simultaneously.

$$\mathcal{L}_{Yukawa} \supset \bar{f}_i\, \rho^f_{ij}\, [H + i\,{\rm sgn}(Q_f) A]\, P_R\, f_j + {\rm h.c.}, \quad (f = u, d, \ell)$$

- *Extra* Yukawa matrices ρ^f are nondigonal and complex. Complexity of $\rho_{\tau\mu}\rho_{\mu\tau}$ will induce muon EDM.
- Defining $\rho_{\tau\mu}\rho_{\mu\tau} = |\rho_{\tau\mu}\rho_{\mu\tau}| \exp(\phi_{CP})$, muon EDM (dashed lines) allowed by muon $g-2$ (red):

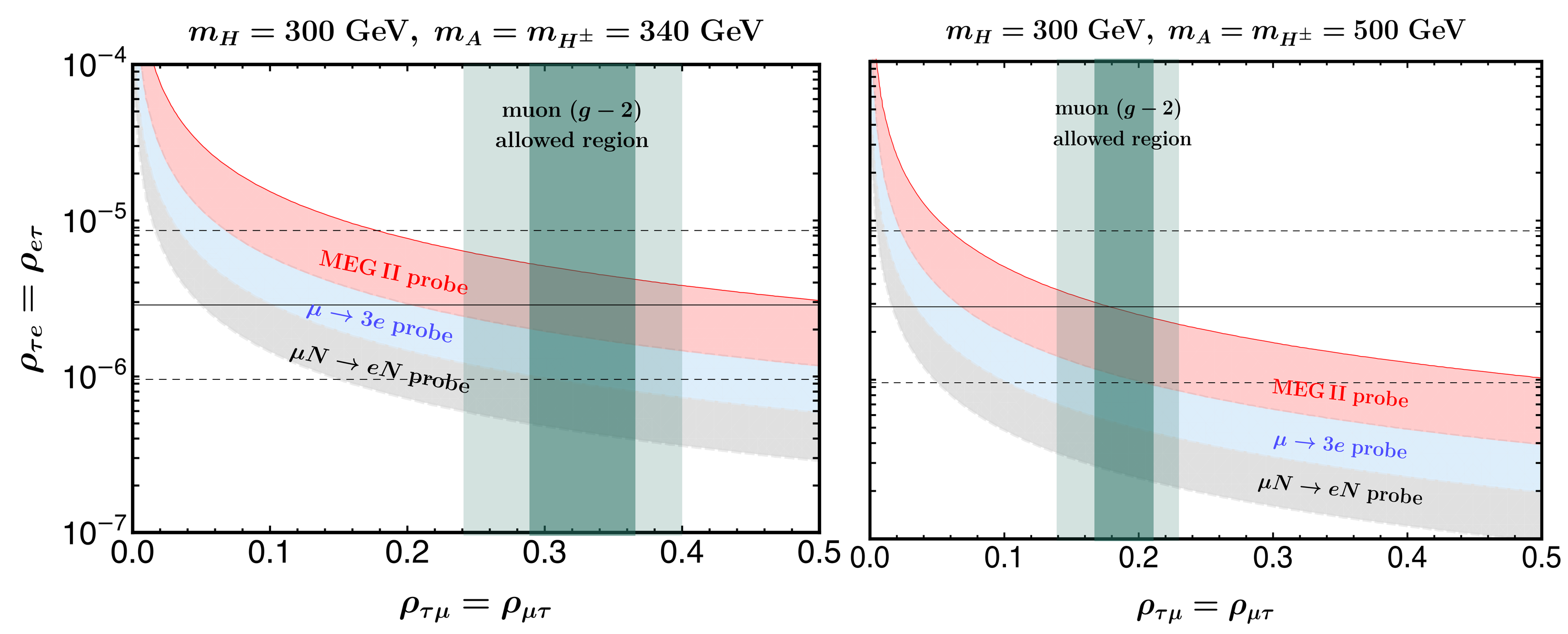


PSI can detect μEDM in g2HDM, if one-loop muon g-2

III. $\mu \to e\gamma$, $\mu \to 3e$, $\mu N \to eN$

- Same one-loop mechanism (with $\ell = e$) generates $\mu \to e\gamma$, which depends on $\rho_{\tau\mu}$ and $\rho_{\tau e}$.
- MEG bound $\mathcal{B}(\mu \to e\gamma) < 4.2 \times 10^{-13}$ already rules out $\rho_{\tau e} \gtrsim 3\lambda_e$.

MEG II can detect $\mu \to e\gamma$ for $\rho_{\tau e} \simeq \lambda_e$ ($\simeq 3 \times 10^{-6}$)!!



- $\mu e\gamma$ dipole probed further by $\mu \to 3e$ and $\mu N \to eN$, even if $\rho_{\tau e}$ order of magnitude smaller than λ_e.

$$\frac{\mathcal{B}(\mu \to 3e)}{\mathcal{B}(\mu \to e\gamma)} \simeq \frac{\alpha}{3\pi}\left(\log\frac{m_\mu^2}{m_e^2} - \frac{11}{4}\right); \qquad \Gamma_{\mu\to e} \simeq \pi D^2\, \Gamma(\mu \to e\gamma)$$

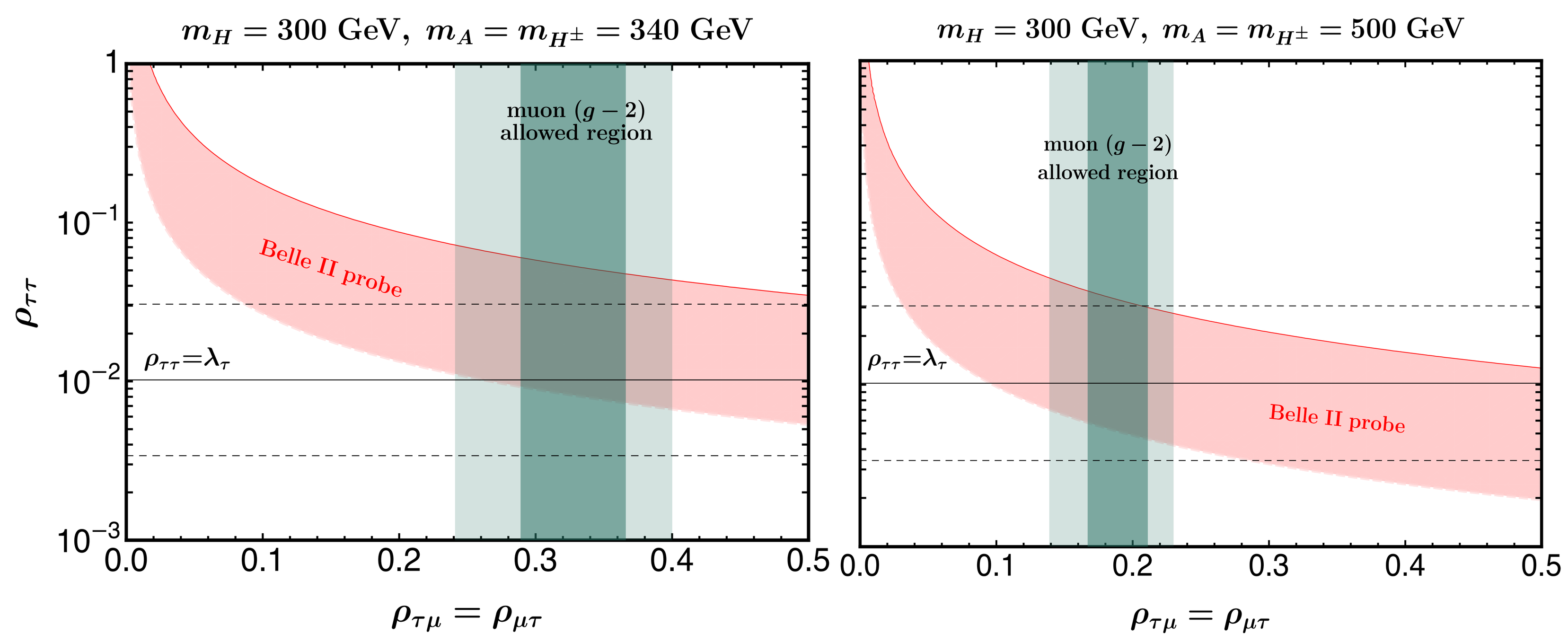
D related to lep-nucleus overlap integral

- $\mu N \to eN$ esp. important: access ρ_{qq} quark couplings via tree-level H, A exchange, by varying Z, A.

IV. $\tau \to \mu\gamma$

- $\rho_{\tau\mu}$ and $\rho_{\mu\tau}$ will also induce $\tau \to \mu\gamma$ if $\rho_{\tau\tau}$ present.
- Belle limit $\mathcal{B}(\tau \to \mu\gamma) < 4.2 \times 10^{-8}$ hints at $\rho_{\tau\tau} < (3-5)\lambda_\tau$.

Belle II can detect $\tau \to \mu\gamma$ for natural value $\rho_{\tau\tau} \sim \lambda_\tau$



- $\tau\mu\gamma$ dipole also probed by $\tau \to 3\mu$, but $\tau \to \mu\gamma$ is leading, in contrast to $\mu \to e$ sector.

V. Caveat: alignment limit?!

- $h \to \tau\mu$ search $\implies$ $|\rho_{\tau\mu} c_\gamma| \lesssim 0.1\lambda_\tau$;
  Large $\rho_{\tau\mu} \sim 20\lambda_\tau$ for muon $g-2$ $\implies$ c_γ vanishing.
- Recall *fermion mass-mixing hierarchy* also not anticipated:
  $m_1 \ll m_2 \ll m_3$; $|V_{ub}|^2 \ll |V_{cb}|^2 \ll |V_{tb}|^2$; $m_b/m_t \ll 1$.
- $c_\gamma \to 0$: a new symmetry in Higgs sector to protect flavor!?
  N.B.: Alignment (small c_γ) itself emergent (not anticipated).

VI. Discussion

- If $\rho_{\tau\mu}$ not large, but $\sim \lambda_\tau$, then one-loop mechanism mute.
  $\implies$ Two-loop Barr-Zee diagrams dominate $\mu \to e$, $\tau \to \mu$ processes.
- Extra Top Yukawa $\rho_{tt} \sim \lambda_t$ together with $\rho_{\tau\mu} = \rho_{\mu\tau} \sim \mathcal{O}(\lambda_\tau)$ induce $\tau \to \mu\gamma$ accessible at Belle II. [WSH/GK, PRD 102 (2020) 115017]
- Similarly, $\rho_{\mu e} = \rho_{e\mu} \sim \mathcal{O}(\lambda_e)$ gives $\mu \to e\gamma$ measurable at MEG II.

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