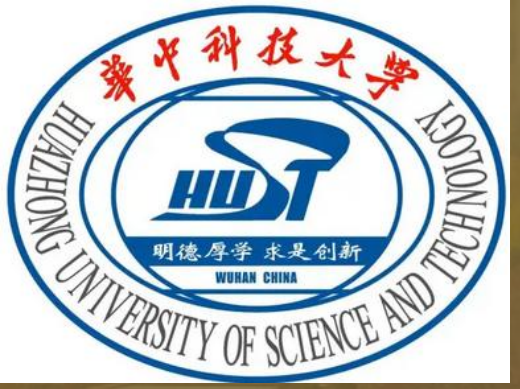


30th Mini-workshop on the frontier of LHC
5/24/2025/洛阳

A light LFV flavon

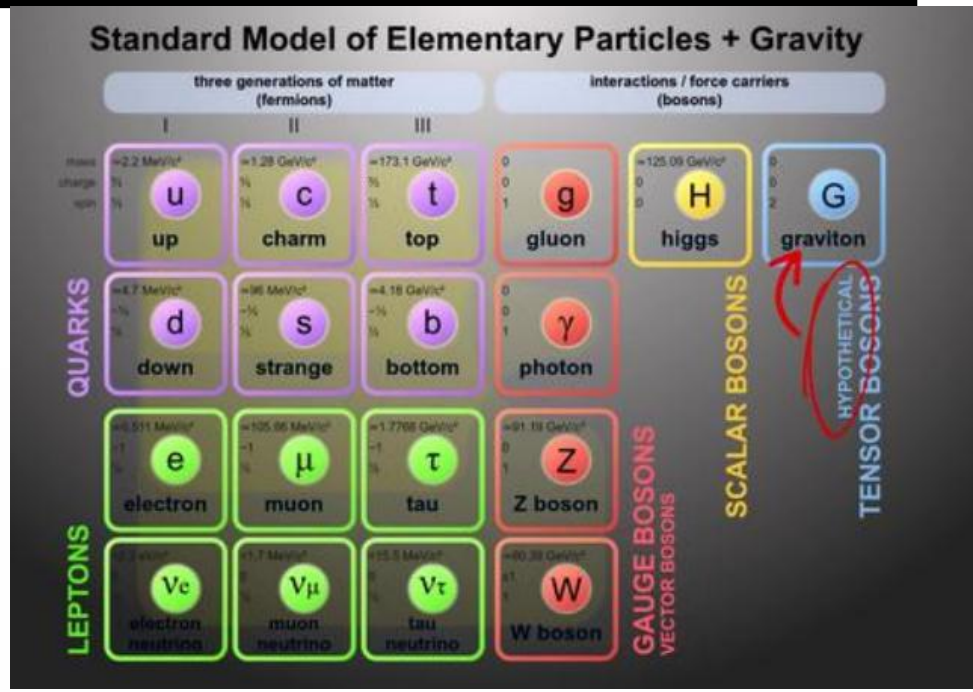
the Messenger of neutrino mixing & $(g-2)_\mu$

Zhaofeng Kang/华中科技大学

Based on work 2504.12070, Shuyang Han and Zhaofeng Kang

An old puzzle of SM: why 3 families?

Three generations of fermions under the Anthropic Principle



1rd & the basis: the visible world is built upon u, d and e, which are bounded into the neutral composites by gluons and photons, providing materials for the God

3rd & matter asymmetry?: top quark thus the 3rd family is important to generate baryon asymmetry in the baryogenesis mechanism

2rd & dark matter?: Quark nuggets consists of u, d, s may provide a dark matter candidate without requiring new physics

An old puzzle of SM: why 3 families?

More usage of 3 generations structure: providing a powerful probe to new physics due to the almost absence of FCNC

Gauge interactions are **family-blind & fermions obtain mass from a single Higgs doublet**, leading to one of the most remarkable feature of SM: no-family-crossing at tree-level and extremely suppressed by W-loop and GIM mechanism!

In the quark sector, the current experiments on the FCNC involving **the first two generations in the down sector** are particularly strong

But FCNC easily arises in the extended SMs, by other iso-multiplets, other Higgs or gauge bosons

Specific to the leptonic sector, the lepton flavor violation (LFV) like $\mu \to e\gamma$, $\mu \to 3e$ etc. place very strong bounds

Anomalies or smoking guns of the FCNC process from LHCb?

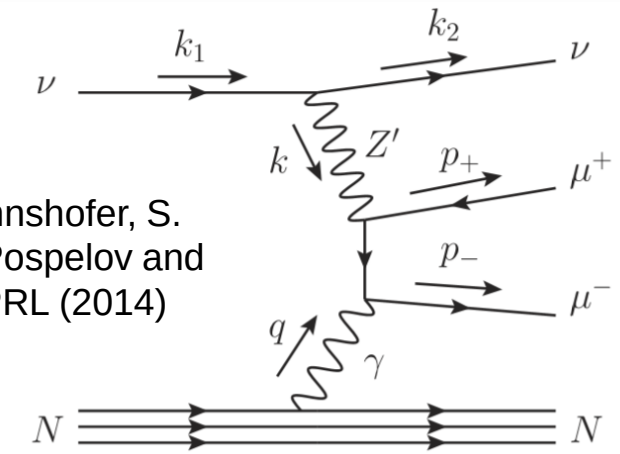
e-phobic Z' from family-sighted local B-L extension

not very strongly motivated, but it provides a playground for flavor anomalies, e.g., $(g-2)_\mu$ discrepancy $\Delta a_\mu = (251 \pm 59) \times 10^{-11}$

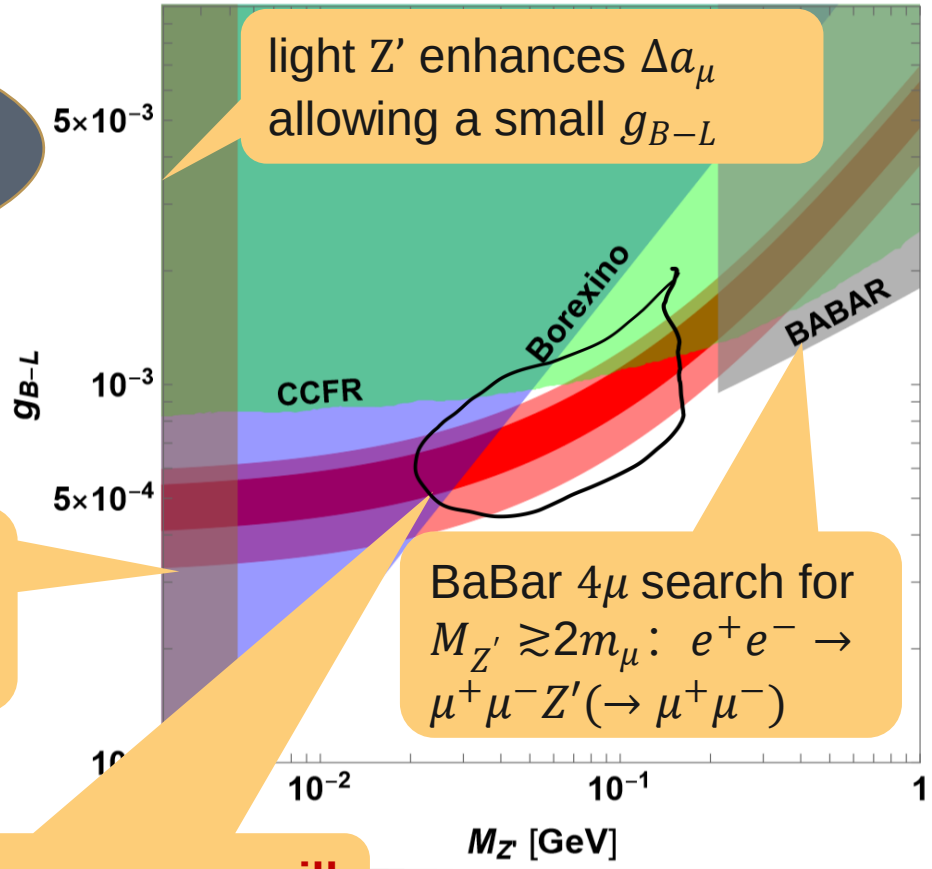
Z_{B-L} from family-blind local B-L does not work, but an **e-phobic muon force from local $(B-L)_{23}$** may open a space hidden far below the weak scale world

Z. Kang and Y. Shigekami, JHEP 11, 049 (2019).

$$-\mathcal{L}^l_{Z'} = -g_{B-L}(\bar{\mu}\gamma^\mu\mu + \bar{\tau}\gamma^\mu\tau + \bar{\nu}_\mu\gamma^\mu\nu_\mu + \bar{\nu}_\tau\gamma^\mu\nu_\tau)Z'_\mu,$$



W. Altmannshofer, S. Gori, M. Pospelov and I. Yavin, PRL (2014)



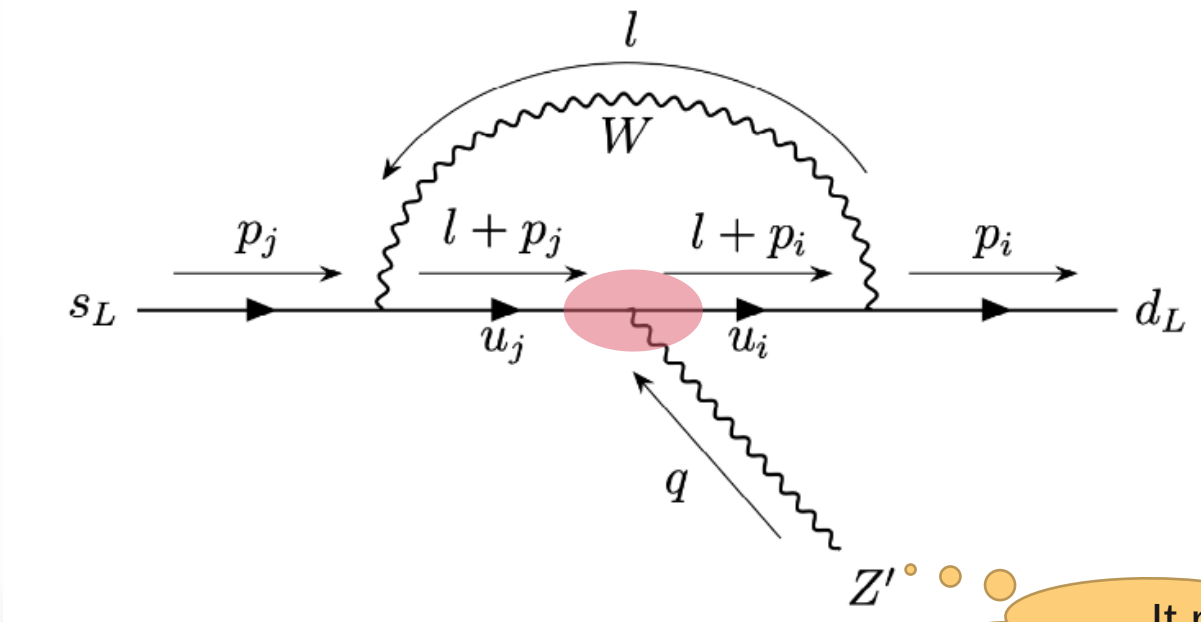
CCFR Neutrino trident production: rule out a heavy $M_{Z'} \gtrsim 0.4\text{GeV}$

If not e-phobic, then **$e\nu_\mu \to e\nu_\mu$ will close this window** by Borexino

e-phobic Z' from family-sighted local $B-L$ extension

Although tree level FCNC occurs only in the up quark sector $t \to cZ'$, loop FCNCs in the down quark sector are induced via the charged current, e.g., $K \to \pi + Z'(\to \nu\bar{\nu})$

higekami, JHEP 04, 238 (2021).



It may threaten the scenario of e-phobic Z_{B-L}

A flavon messenger in the family-sighted models

A flavon field spontaneously breaking the family symmetry, with vector-like leptons, required to generate full neutrino mixings. Then a light LFV flavon may solve $(g-2)_\mu$ puzzle. E.g., in $(B-L)_{13}$

$$-\mathcal{L}_L = Y^e_{22}\bar{\ell}_2 H e_{R2} + Y^e_{ij}\bar{\ell}_i H e_{Rj} + Y^N_{ij}\bar{\ell}_i \tilde{H} N_{Rj} + Y^e_i \overline{L}_L H e_{Ri} + Y^N_i \overline{L}_L \tilde{H} N_{Ri}$$
$$+ \lambda^\ell_2 \bar{\ell}_2 L_R \mathcal{F}^*_\ell + M^\ell_i \bar{\ell}_i L_R + m_L \overline{L}_L L_R + \frac{\lambda^N_{ij}}{2}\Phi \bar{N}^C_{Ri} N_{Rj} + h.c.\,,$$

Related to $(B-L)_{13}$, the selected LFV pattern for flavon is $\mathcal{F}(=s\pm ia)\bar{\mu}\boldsymbol{P_R}e/\tau$

Occam's razor principle

$$M_e \equiv \begin{pmatrix} \frac{v_h}{\sqrt{2}}Y^e_{11} & 0 & 0 & M^\ell_1 \to 0 \\ 0 & \frac{v_h}{\sqrt{2}}Y^e_{22} & 0 & M^\ell_2 \\ 0 & 0 & \frac{v_h}{\sqrt{2}}Y^e_{33} & M^\ell_3 \to 0 \\ \frac{v_h}{\sqrt{2}}Y^e_1 & 0 & \frac{v_h}{\sqrt{2}}Y^e_3 \to 0 & m_L \end{pmatrix}$$

$M^\ell_2 = \lambda^\ell_2 v_f/\sqrt{2}$ is related to flavor symmetry breaking, to account **for the full neutrino mixing**

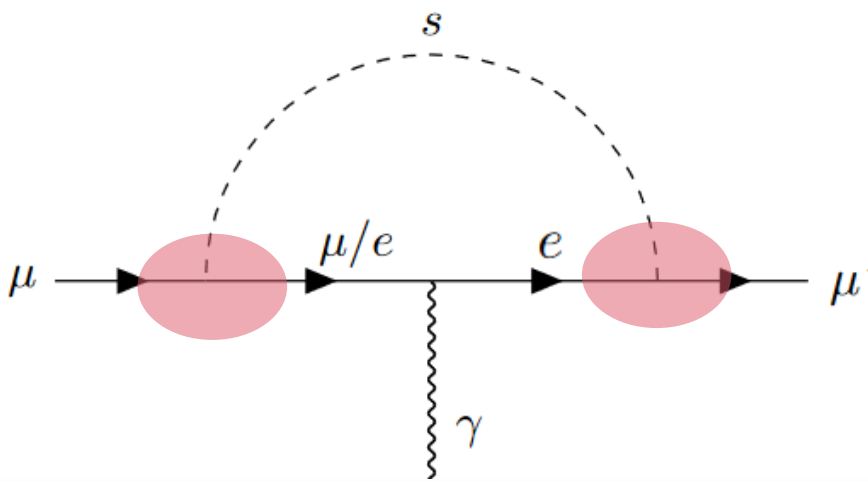
It generates LFV coupling flavon-$e-\mu$ via $(U_R)_{41} \simeq Y^e_1 v_h/m_L$

At the same time, this mixing element will be adjustable to suppress the charged lepton flavor violating decay

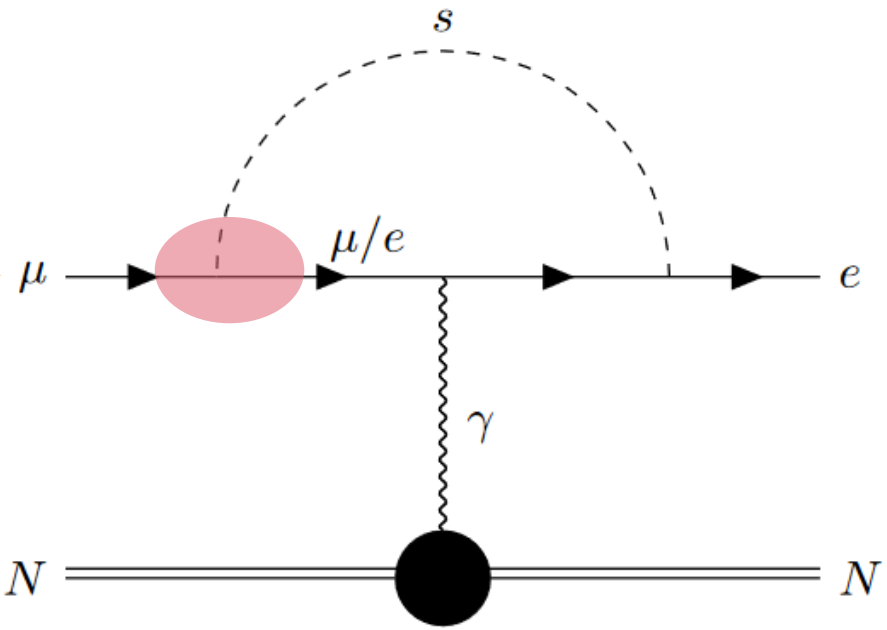
Alternatively, turn on this element leads to LFV flavon coupling to $\tau\mu$

Plays fire: LFV flavon solution & LFV signature

The LFV flavon offers an interesting solution to the $(g-2)_\mu$ puzzle and moreover leaves with cross-checking signatures in the leptonic FCNC process



$(g-2)_\mu$ & $\mu \to e\gamma$ is strongly correlated

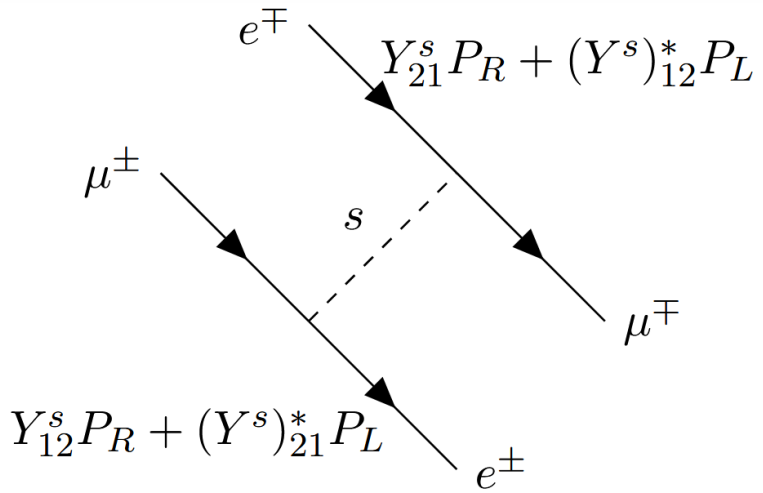


CR(μ-e, N)	4.3×10^{-12}	(N = Ti)	[25]
	4.6×10^{-11}	(N = Pb)	[26]
	7×10^{-13}	(N = Au)	[27]

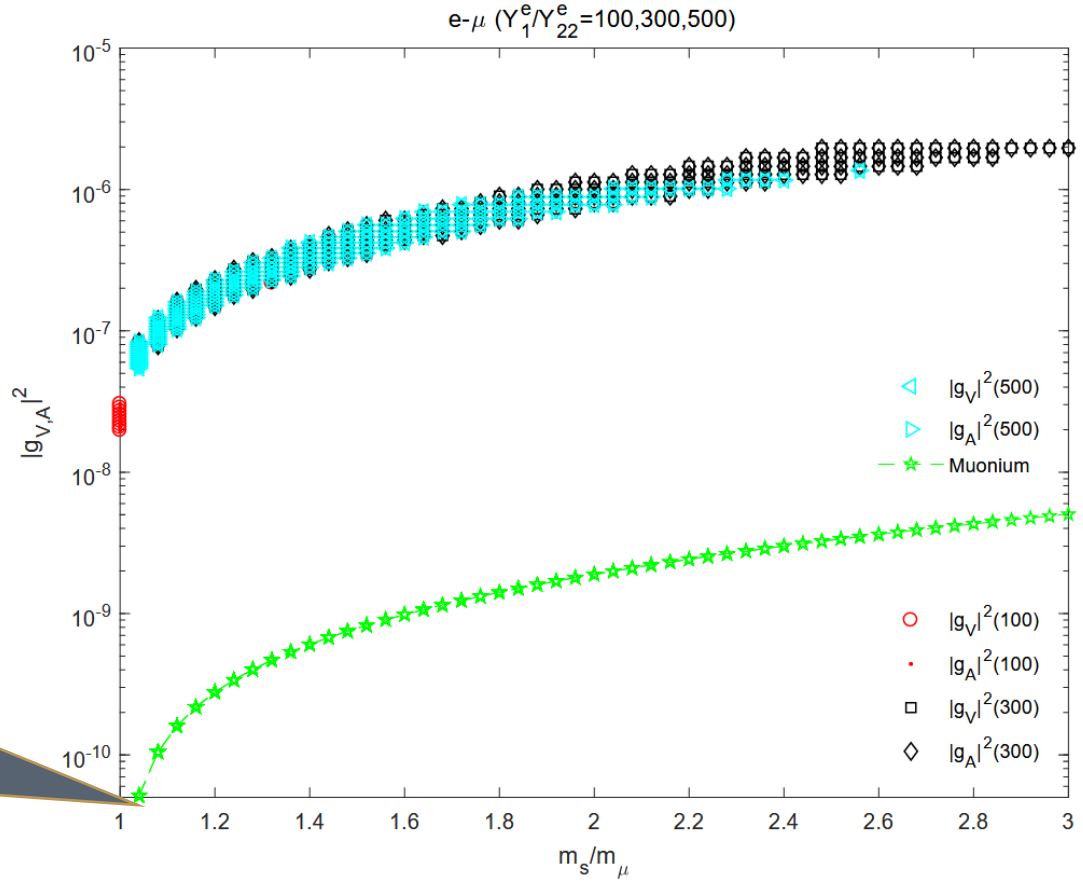
Put out the fire: the μe-type LFV flavon

Muonimum (M)-$\overline{\text{Muonimum}}$ ($\bar{M}$) oscillation: a killer for $e-\mu$ conversion

Muonimum is a **hydrogen-like** bound state of $\mu^+e^- \leftrightarrow \mu^-e^+$ mediated by flavon

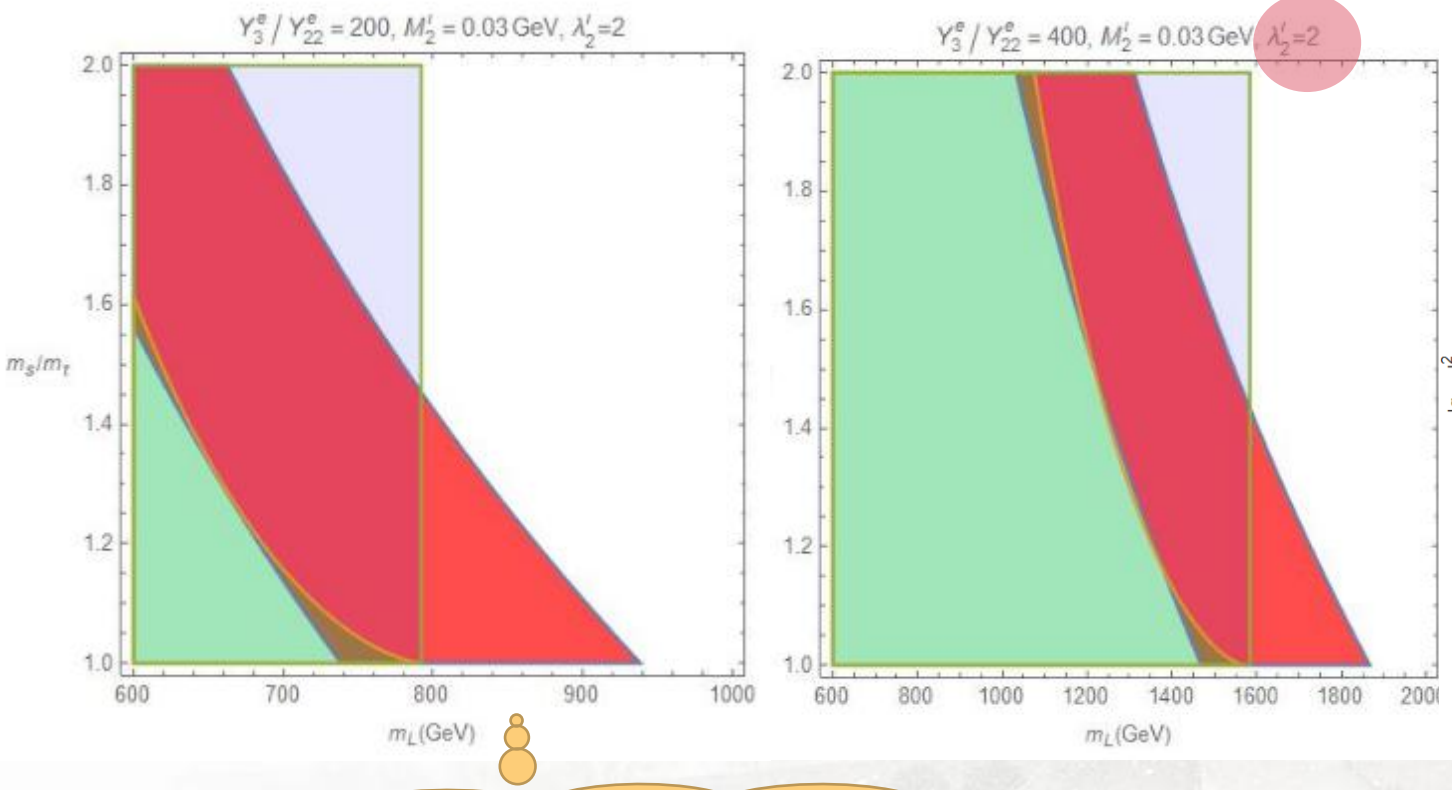


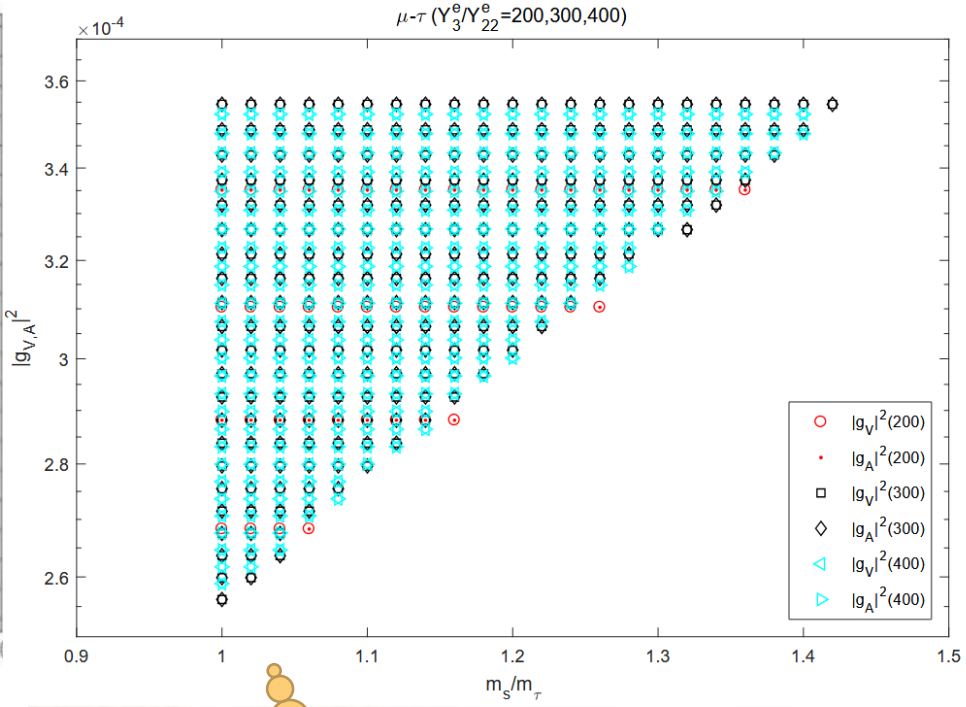
The MEG (98) imposes the upper bound on the oscillation probability $P_{M\bar{M}} < 8.2 \times 10^{-11}$ at 90%, yielding **a direct constraint** on $s\bar{\mu}e$



Remaining spark: the $\mu\tau$-type LFV flavon

The $(g-2)_\mu$ enhancement from the $s-\mu-\tau$ loop is not the optimal due to $m_\tau \gg m_\mu$, but it is free of $M-\bar{M}$ oscillation





TeV scale VL lepton: $pp \to e_4^- (\to s\mu^-) + e_4^+ (\to s\mu^+)$ with boosted $s \to \mu^\pm\tau^\mp$ or invisible?

Surviving LFV flavon within $[m_\tau, 1.5m_\tau]$ window & $s\mu\tau$ coupling$\sim O(1)10^{-4}$: future Babar? planed μTRISTAN? CEPC?

THANKS