Theoretical models of neutrino masses

1st June 2022

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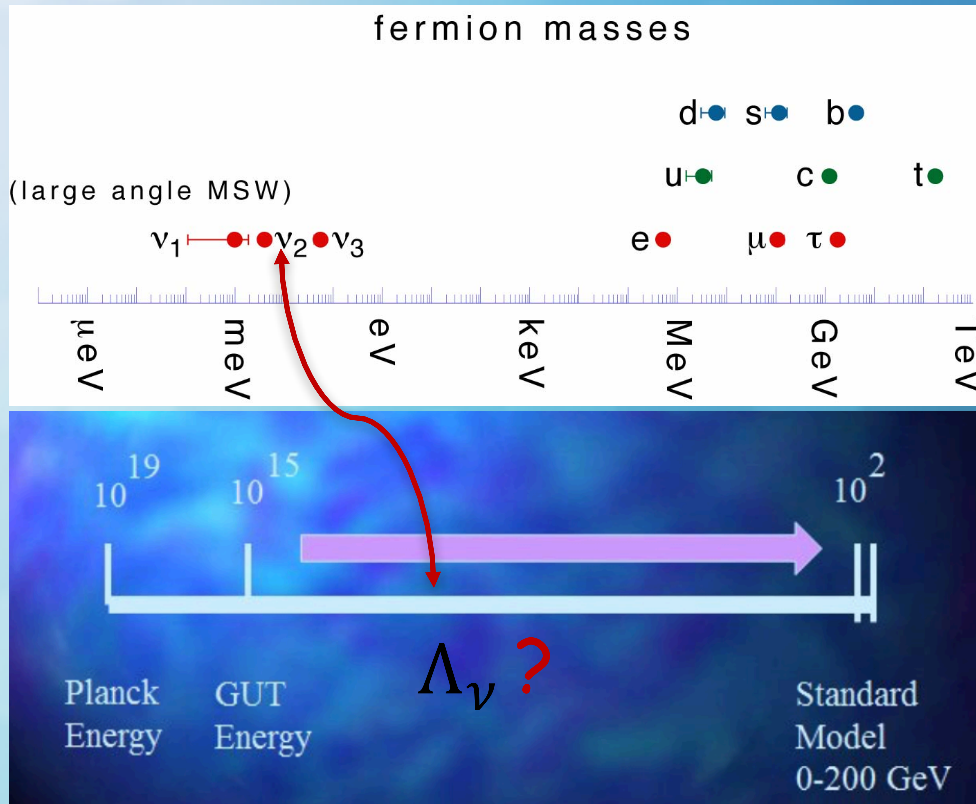
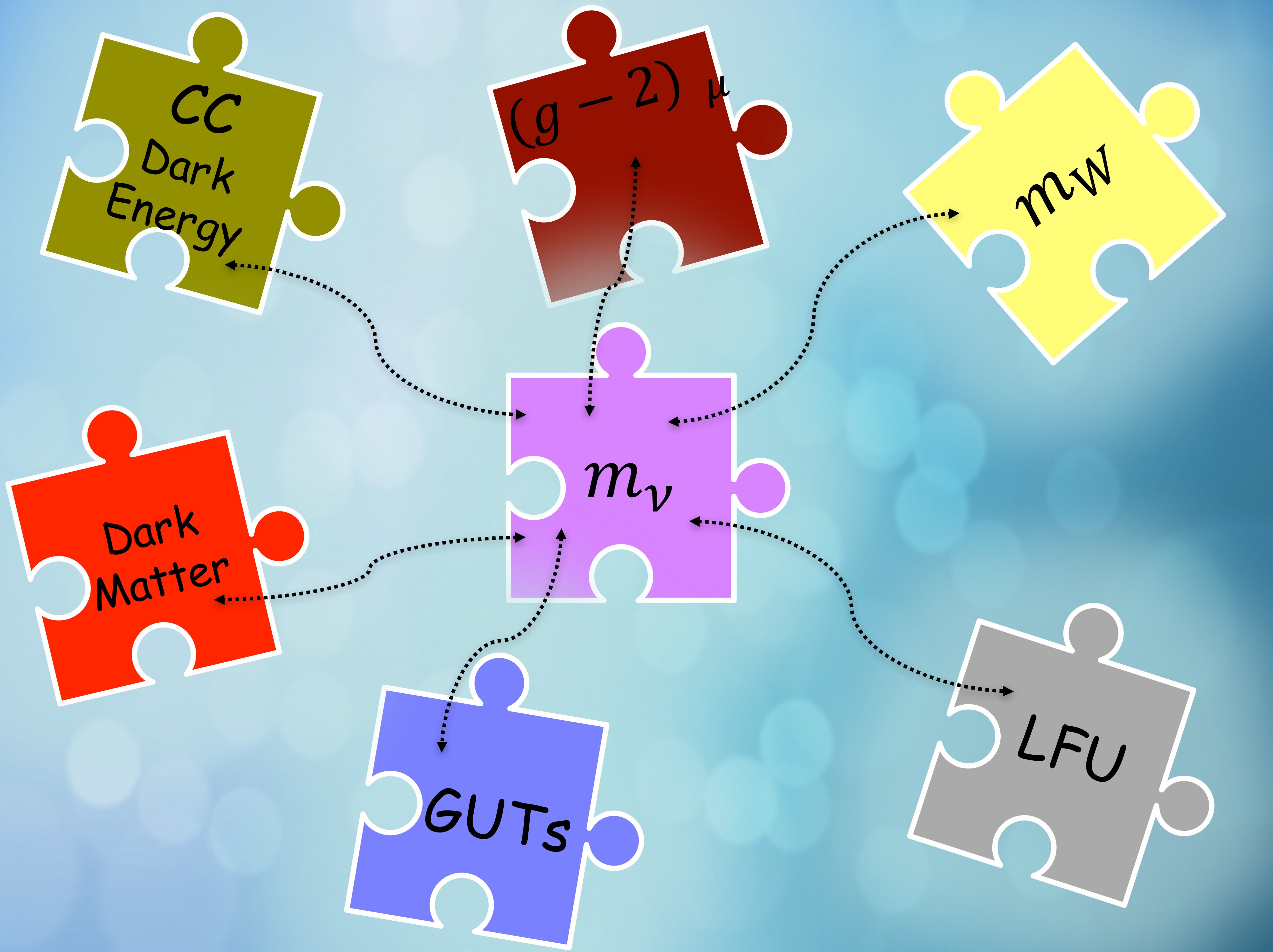
two (among many) open questions

- mechanism of neutrino mass generation



- peculiar mixing pattern and flavour symmetries

$$\begin{pmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{pmatrix} = \begin{pmatrix} \textbf{PMNS} \\ \textbf{matrix}\end{pmatrix}\begin{pmatrix}\nu_1\\ \nu_2\\ \nu_3\end{pmatrix}$$


CC
Dark
Energy
$(g-2)\ \mu$
m_W
m_ν
Dark
Matter
GUTs
LFU

which mass scale?

$$\mathcal{L} = \mathcal{L}_{SM} + \nu^c\, \mathcal{Y}_\nu (H\ell) + \ell\, \mathcal{C}_4 \ell \Delta$$

d=4

which mass scale?

$$\mathcal{L} = \mathcal{L}_{SM} + \nu^c\, \mathcal{Y}_\nu (H\ell) + \ell\, \mathcal{C}_4 \ell \Delta$$

$$+ \frac{1}{\Lambda_5} (H\ell)\, \mathcal{C}_5\, (H\ell)$$

$$+ \frac{1}{\Lambda_6^2} \overline{(H\ell)}\, \mathcal{C}_6\, \gamma^\mu \partial_\mu (H\ell) + \cdots$$

d=4

d=5

d=6

which mass scale?

$$\mathcal{L} = \mathcal{L}_{SM} + \nu^c\, \mathcal{Y}_\nu (H\ell) + \ell\, \mathcal{C}_4 \ell \Delta$$

$$+ \frac{1}{\Lambda_5} (H\ell)\, \mathcal{C}_5\, (H\ell)$$

$$+ \frac{1}{\Lambda_6^2} \overline{(H\ell)}\, \mathcal{C}_6\, \gamma^\mu \partial_\mu (H\ell) + \cdots$$

d=4

d=5

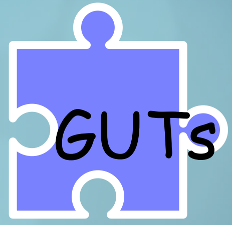
d=6

most plausible option: d=5

$$m_\nu \approx v\, \frac{v}{\Lambda_5}$$

$$m_\nu \approx \sqrt{\Delta\, m^2_{atm}}$$

$$\Lambda_5 \approx 10^{15}\ \text{GeV}$$



smallness of m_ν due to Λ_5 very large

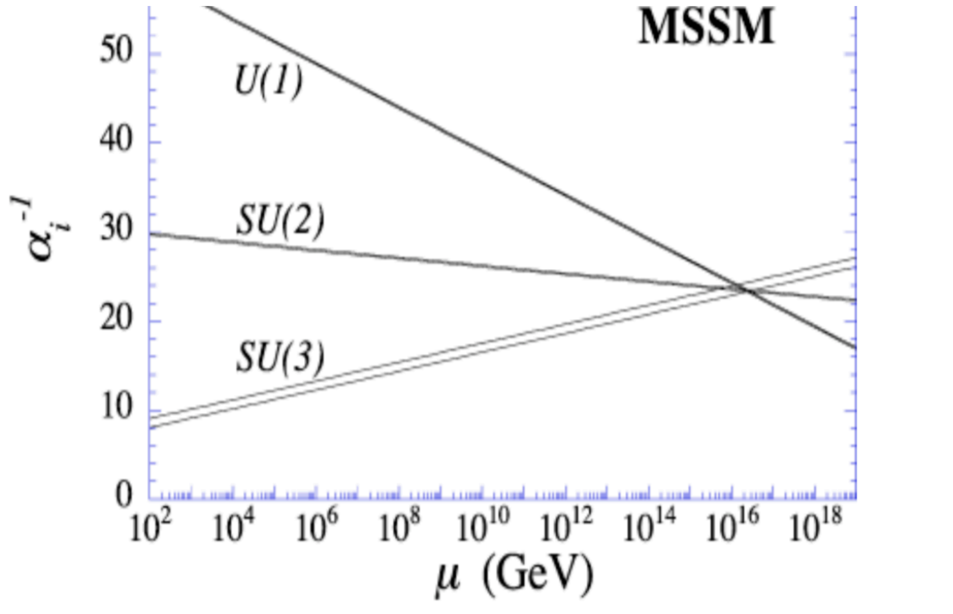
unique window on physics at very large scales,
inaccessible in present man-made experiments

independent indication of a new physics threshold close to GUT scale

SO(10) GUT: 16 = (1 SM family + ν^c)

heavy ν^c exchange give rise to
(a specific version of) d=5

see-saw $$\frac{\mathcal{C}_5}{\Lambda_5} \approx y_\nu^T M^{-1} y_\nu$$



d=5 breaks (B-L) by two units

B-L violated, in general, when unifying particle interactions (in GUTs and by quantum gravity)

(B-L) violation welcome in baryogenesis

baryogenesis through out-of-equilibrium, CP and (B-L)-violating decays of heavy ν^c

m_ν related to m_W anomaly?

m_W

- $(m_W)_{CDF} = 80{,}433.5(9.4) MeV$
- $(m_W)_{SM} = 80{,}354.5(5.7)\ MeV$

$\Delta = (1,3,+1)$

$\mathcal{L} = \mathcal{L}_{SM} + \ell\, \mathcal{C}_4 \ell \Delta$

$$\frac{\delta\, m_W^2}{m_W^2} = -\frac{2\cos^2\theta}{\cos 2\theta}\ \frac{\langle\Delta\rangle^2}{v^2} + \text{loops}$$

[Heeck 2204.10274]

wrong sign

$\langle\Delta\rangle < 1\ GeV$

$100\ GeV \leq\ m_\Delta\ \leq 300\ GeV$

- $\mathcal{C}_4 \approx \frac{m_\nu}{\langle\Delta\rangle} \ll 1$

to suppress $\mu\ \to\ e\gamma$
and $\Delta^{++}\ \to \ell^+\ell^+$

$1\, MeV\ < \langle\Delta\rangle < 1\, GeV$

$10^{-11} <\ \mathcal{C}_4 < 10^{-8}$

- no clue on smallness of m_ν

- tests $\quad 0.1\, pb < \sigma(pp \to \Delta^{++}\Delta^{--}) < 1\, pb$

m_ν related to m_W anomaly?

$$\mathcal{L} = \mathcal{L}_{SM} + \frac{1}{\Lambda_5}(H\ell)\mathcal{C}_5(H\ell) + \frac{1}{\Lambda_6^2}\overline{(H\ell)}\mathcal{C}_6\gamma^\mu\partial_\mu(H\ell) + \cdots$$

relevant e.g. in inverse seesaw

$$\frac{\mathcal{C}_5}{\Lambda_5} \approx y_\nu^T M^{-1}\mu\, M^{-1} y_\nu$$

$$\frac{\mathcal{C}_6}{\Lambda_6^2} \approx y_\nu^+ M^{-1}\, M^{-1} y_\nu$$

- lepton mixing matrix no more unitary

$$\mathcal{U}_{fi} \to \left(\delta_{ff'} - \eta_{ff'}\right)\mathcal{U}_{f'i}$$

$$\eta_{ff'} = \frac{\mathcal{C}_6}{4}\frac{v^2}{\Lambda_6^2} \qquad \eta_{ff} > 0$$

- $$\frac{\delta\, m_W^2}{m_W^2} = +\frac{\sin^2\theta}{\cos 2\theta}\,\frac{\delta G_F}{G_F} = +\frac{\sin^2\theta}{\cos 2\theta}\underbrace{\left(\eta_{ee} + \eta_{\mu\mu}\right)}_{\approx\, 2\cdot 10^{-3}}$$

right sign

$M \approx y_\nu\, 3.9\, TeV$

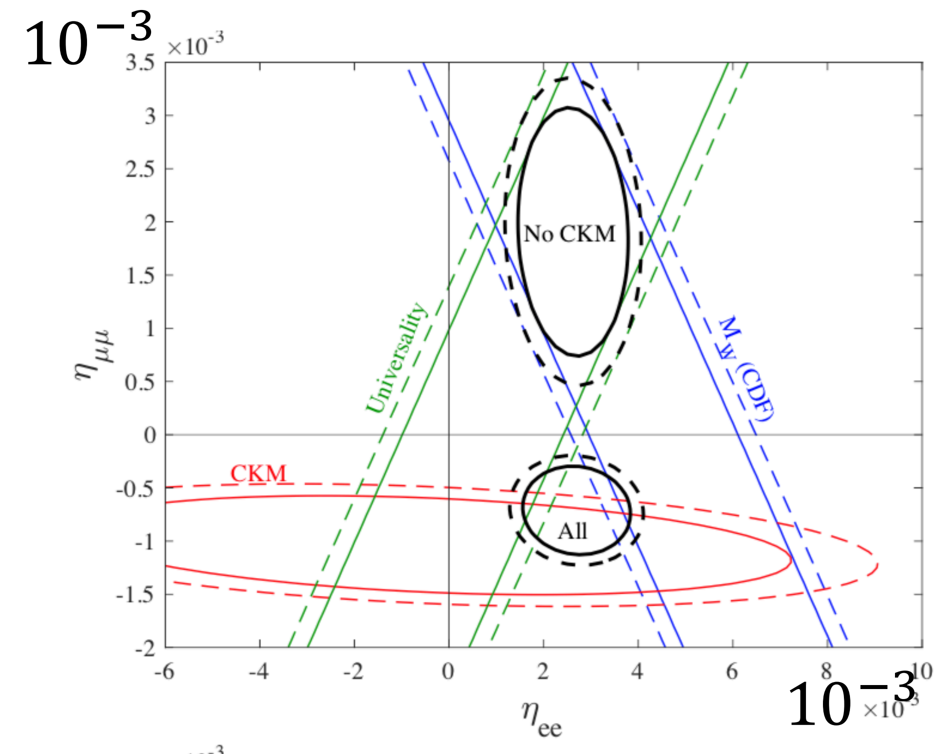
mixing active/sterile ~ 0.1

$\mu \approx \mathcal{O}(10\, eV)$

LFU in π, K, τ decays

[Blennow, Coloma, Fernandez-Martinez,Gonzalez-Lopez, 2204.04559]

$$\eta_{ee} \approx \eta_{\mu\mu}$$



$$1 - |V_{ud}|^2 - |V_{us}|^2 - |V_{ub}|^2 = (1.5 \pm 0.6) \times 10^{-3}$$ PDG2020

$$V_{ud} = (V_{ud})_{EXP}\,(1 - \eta_{\mu\mu})$$

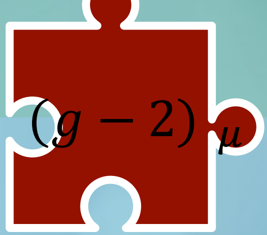
forbidden in minimal framework $\quad \eta_{\mu\mu} < 0$

$$BR(\mu \to e\gamma) \approx \frac{3\alpha}{2\pi}|\eta_{e\mu}|^2 < 4.2\times10^{-13}$$

$$|\eta_{e\mu}| \leq \mathcal{O}(10^{-5}) \quad \Leftrightarrow \quad \eta_{ee} \approx \eta_{\mu\mu} \approx \mathcal{O}(10^{-3})$$

[Fernandez-Martinez, Hernandez-Garcia, Lopez-Pavon 1605.08774]

m_ν related to $(g-2)_\mu$ anomaly?



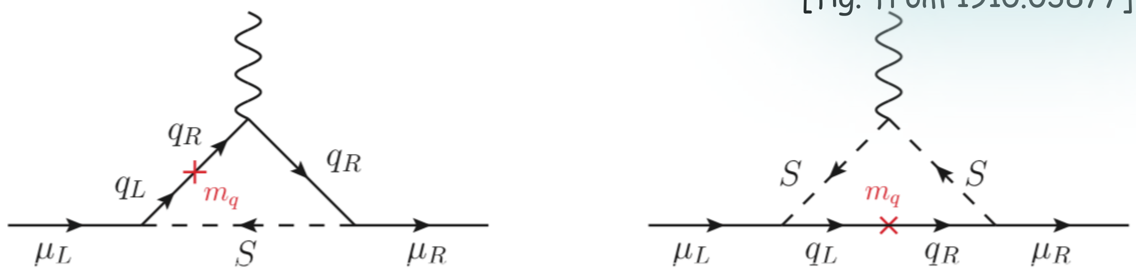
- $\Delta a_\mu = +2.51(59)\ 10^{-9}$

- can be produced by scalar LQ exchange

chiral enhancement:

$\approx m_{top}/m_\mu$

[fig. from 1910.03877]



$S_1 = (\bar{3}, 1, +1/3)$

$R_2 = (3, 2, +7/6)$

[not automatically p-decay free]

[Djouadi, Kohler, Spira, Tutas, 1990
Chakraverty, Choudhury, Datta 0102180
Cheung 0102238
Biggio, Bordone 1411.6799]

- can help explaining part of LFUV in B decays

- scalar LQ exchange

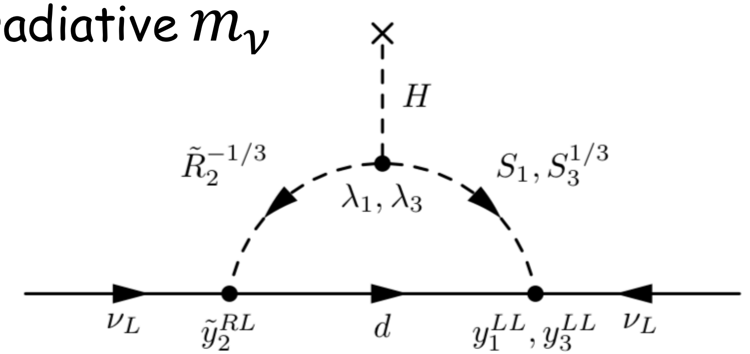
as in the Zee model

$$\eta^+ \to S_1 = \left(\bar{3}, 1, \frac{1}{3}\right)$$

$$H_2 \to \tilde{R}_2 = \left(\bar{3}, 2, \frac{1}{6}\right)$$

[fig. from 1701.08322]

radiative m_ν



[Klein, Lindner, Ohmer 1901.03225]

$$\Delta\mathcal{L} = S_1\, q\, y_1 \ell + \bar{S}_1\, u^c\, y_1'\, e^c + \tilde{R}_2 d^c\, y_2\, \ell$$

[Di Zhang 2105.08670]

$$m_\nu \approx \frac{3\sin 2\theta}{32\pi^2} \log\left(\frac{M_2^2}{M_1^2}\right) \left(y_2^T \hat{m}_d y_1 + y_1^T \hat{m}_d y_2\right)$$

$m_\nu \approx 0.05$ eV $\Rightarrow$ $(y_2)_{3i}(y_1)_{3j} \approx 10^{-9}$

$\Delta a_\mu = +2.51(59)\ 10^{-9}$ $\Rightarrow$ $(y_1)_{32}(y_1')_{32} \approx -5\times 10^{-3} \left(\frac{M_1}{1TeV}\right)^2$

collider bounds

pair production $S_1 \bar{S}_1$
from gg and $q\bar{q}$ at LHV
$S_1 \to t\mu$

$M_1 > 1420\ GeV$

[Angelescu, Becirevic, Faroughy, Sumensari 1808.08179
CMS 1809.05558]

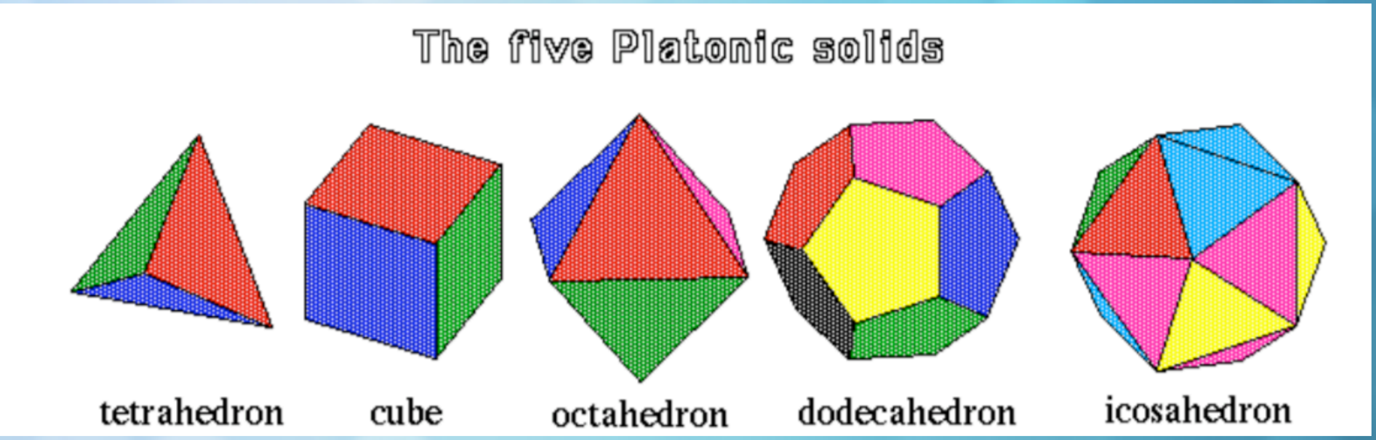
LFV $\mu \to e\gamma$

$$(y_1)_{32}(y_1')_{31}, (y_1)_{31}(y_1')_{32} < 5.4\times 10^{-8} \left(\frac{M_1}{1TeV}\right)^2$$

$$(y_1)_{22}(y_1')_{21}, (y_1)_{21}(y_1')_{22} < 1.3\times 10^{-6} \left(\frac{M_1}{1TeV}\right)^2$$

[Mandal, Pich 1908.11155]

lepton mixing and flavour symmetries



“traditional” Flavour Symmetries

$g \in G_{fl}$

$$\Psi \xrightarrow{g} \varrho(g)\,\Psi$$
$$\Psi^c \xrightarrow{g} \varrho_c(g)\,\Psi^c$$

$$\Psi = \begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} \ldots$$

$\Psi^c\,\mathcal{Y}\,\Psi$

$$\varrho_c^*(g)\,\mathcal{Y}\,\varrho(g)^+ = \mathcal{Y}$$

can be combined with CP

$$\Psi \xrightarrow{CP} X_{CP}\Psi^*$$

example: Isospin SU(2) in strong interactions $m_p = m_n$

- flavour symmetries of this type are necessarily broken

  - many parameters from symmetry breaking sector

  - vacuum alignment problem $\langle\varphi\rangle$

new type of symmetries

modular transformations

τ a complex scalar field, Im(τ) > 0

$$\tau \xrightarrow{\gamma} \frac{a\tau + b}{c\tau + d}$$

a,b,c,d integers
ad-bc=1

$\gamma = \begin{pmatrix} a & b \\ c & d \end{pmatrix} \in SL(2,\mathbb{Z})$ infinite discrete group

$SL(2,\mathbb{Z})$ always broken: non-linearly realized

$$\Psi \xrightarrow{\gamma} (c\tau + d)^{-k} \varrho(\gamma)\, \Psi$$

- $\varrho(\gamma)$ representation of the group $SL(2,\mathbb{Z}_N)$

N	2	3	4	5	6
$SL(2,\mathbb{Z}_N)$	$S_3{}'$	$A_4{}'$	$S_4{}'$	$A_5{}'$	...

- $\mathcal{Y}(\tau)$ depends on τ to compensate the $(c\tau + d)^{-(k+k_c)}$ factors

very restrictive if the model is SUSY

Example

$SL(2,\mathbb{Z}_3) \approx A_4{}'$

$$\begin{pmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{pmatrix} \to (c\tau+d)^{-1}\rho(\gamma)\begin{pmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{pmatrix}$$

$k_\nu = +1$

~ 3 of $SL(2,\mathbb{Z}_3)$

$$w(\tau,\nu) = \nu\, Y(\tau)\, \nu + h.c.$$

$$(c\tau+d)^{-2}\,\rho(\gamma)^T\, Y(\gamma\tau)\rho(\gamma) = Y(\tau)$$

has a unique solution: modular form

[F.F. 1706.08749]

$$m(\tau) = m_0 \begin{pmatrix} 2Y_1(\tau) & -Y_3(\tau) & -Y_2(\tau) \\ -Y_3(\tau) & 2Y_2(\tau) & -Y_1(\tau) \\ -Y_2(\tau) & -Y_1(\tau) & 2Y_3(\tau) \end{pmatrix}$$

Yukawas completely determined in terms of τ up to an overall constant

no corrections from higher order operators in the exact SUSY limit by scanning τ VEVs the best agreement is obtained for $\tau = 0.0111 + 0.9946i$

	$\frac{\Delta m^2_{sol}}{\Delta m^2_{atm}}$	$\sin^2\vartheta_{12}$	$\sin^2\vartheta_{13}$	$\sin^2\vartheta_{23}$	$\frac{\delta_{CP}}{\pi}$	$\frac{\alpha_{21}}{\pi}$	$\frac{\alpha_{31}}{\pi}$
Exp	0.0292	0.297	0.0215	0.5		–	–
1σ	0.0008	0.017	0.0007	0.1		–	–
prediction	0.0292	0.295	0.0447	0.651	1.55	0.22	1.80

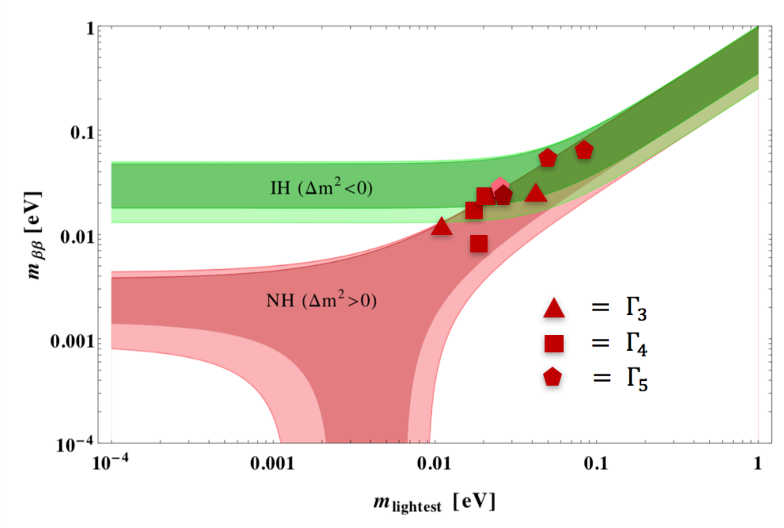
2-parameter fit to
5 physical quantities

many
σ away

8 dimensionless physical quantities independent on any coupling constant!

brought to agreement by a small contribution from the charged lepton

many models with predictive power



solutions with NO prefer $m_1 > 10\, meV$ and $|m_{ee}|$ on the high side of allowed range

Bottom-up modular invariance approaches to the lepton flavour problem have been exploited first using the groups

$\Gamma_3 \simeq A_4$ (F. Feruglio, 1706.08479; J.C. Criado, F. Feruglio, 1807.01125);

$\Gamma_2 \simeq S_3$ (T. Kobayashi et al., 1803.10391);

$\Gamma_4 \simeq S_4$ (J.T. Penedo, S.T. Petcov, 1806.11040, minimal, no flavons).

After these first studies, the interest in the approach grew significantly and models based on different groups have been constructed and extensively studied:

$\Gamma_4 \simeq S_4$
(Novichkov:2018ovf,Kobayashi:2019mna,Okada:2019lzv,Kobayashi:2019xvz,Gui-JunDing:2019wap,Wang:2019ovr,Wang:2020dbp,Gehrlein:2020jnr);

$\Gamma_5 \simeq A_5$
(P.P. Novichkov et al., 1812.02158; Ding:2019xna,Gehrlein:2020jnr);

$\Gamma_3 \simeq A_4$
(Kobayashi:2018scp, Novichkov:2018yse, Nomura:2019jxj, Nomura:2019yft, Ding:2019zxk, Okada:2019mjf, Nomura:2019lnr, Asaka:2019vev, Gui-JunDing:2019wap, Zhang:2019ngf, Nomura:2019xsb, Kobayashi:2019gtp, Wang:2019xbo, Abbas:2020vuy, Okada:2020dmb, Ding:2020yen, Behera:2020sfe, Nomura:2020opk, Nomura:2020cog, Behera:2020lpd, Asaka:2020tmo, Nagao:2020snm, Hutauruk:2020xtk);

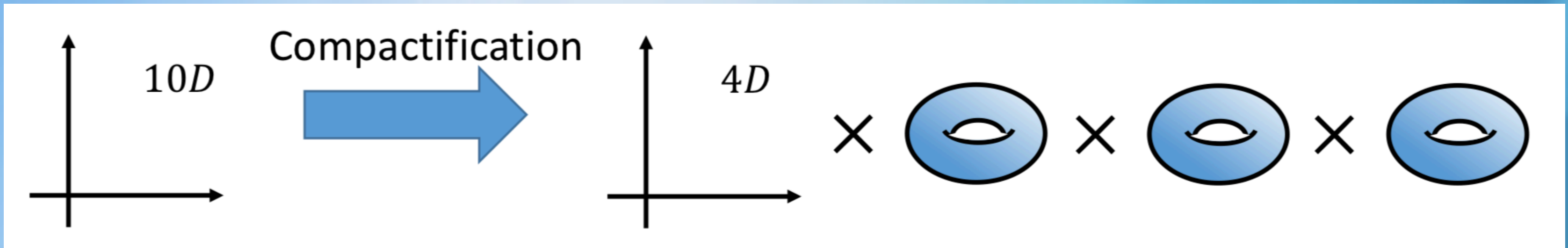
$\Gamma_2 \simeq S_3$ (Okada:2019xqk,Mishra:2020gxg);

$\Gamma_7 \simeq PSL(2, \mathbb{Z}_7)$ (G.-J. Ding et al., 2004.12662).

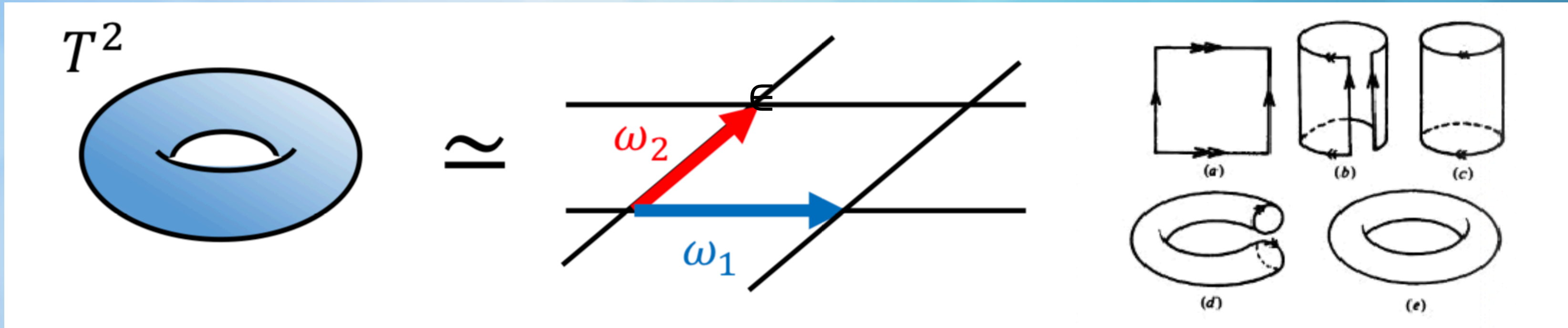
Similarly, attempts have been made to construct viable models of
quark flavour and of quark-lepton unification (including based on GUTs):

geometrical interpretation

string theory in d=10 need 6 compact dimensions



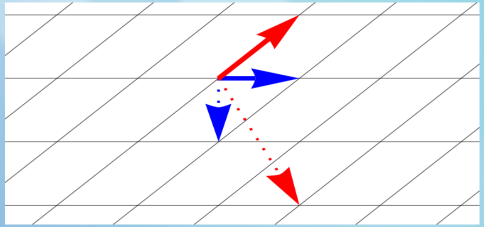
simplest compactification: 3 copies of a torus T^2



tori parametrized by

$$\mathcal{M} = \left\{ \tau = \frac{\omega_2}{\omega_1} \quad Im(\tau) > 0 \right\}$$

lattice left invariant by modular transformations:



$$\tau \to \gamma\tau \equiv \frac{a\tau + b}{c\tau + d} \in SL(2,Z)$$

a, b, c, d integers

$ad - bc = 1$

conclusion

- Neutrino mass generation:
  no evidence but several mechanisms interesting to explore

Learn more at Neutrino 2022 poster session:

Enrique Arrieta-Diaz, Xin Wang, Soumita Pramanick,
Xu Li, Driya Mishra, Papia Panda, Camilo Cortes Pana,
Mitesh Behera, Yuta Hyodo, Manuel Ettemberg, Nicolas Benoit

- Flavour symmetries: a non conventional realization?

  - relation to string theories:

    [Nilles, Ramos-Sanchez, Trautner, Vaudrevange, Chen, Knapp-Perez, Ramos-Hamud, Ramos-Sanchez, Ratz and Shukla, Kobayasji, Otsuka,...]

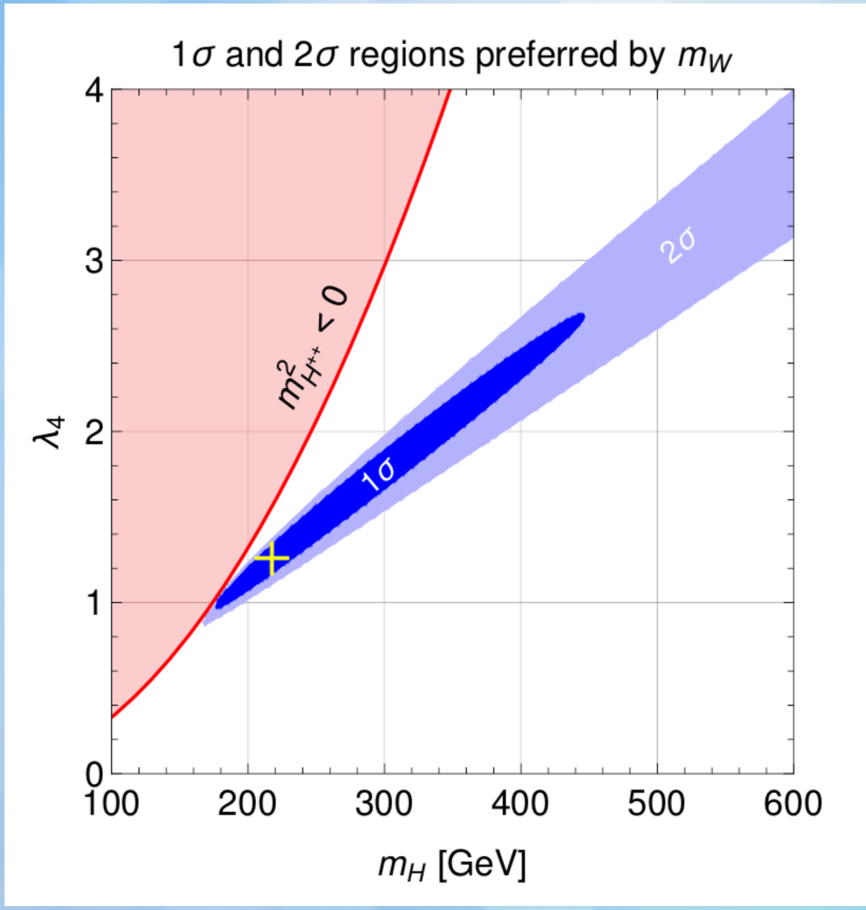
  - Modular invariance and CP violation
  - Modular invariance and fermion mass hierarchy
  - Modulus stabilization

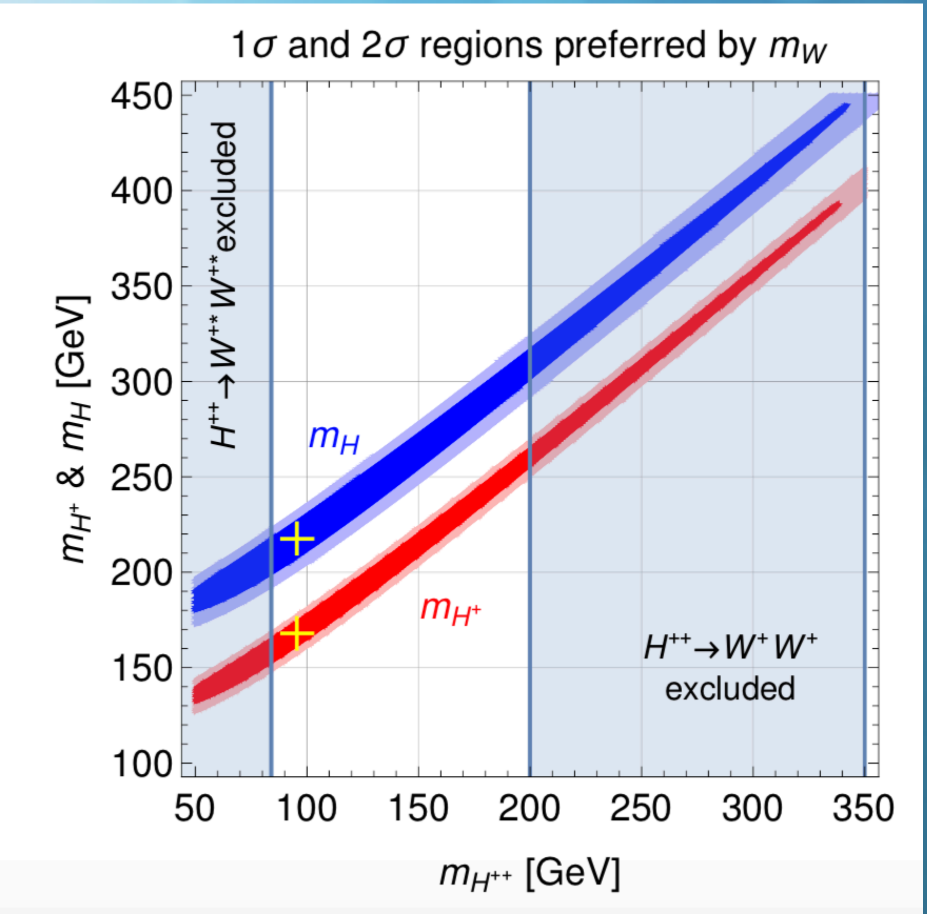
    [Gherardi, Romanino, King, Novichkov, Penedo, Petcov, Titov, Ding, Liu, Tanimoto,...]

THANK YOU!

back-up slides

$$\mathcal{L} = \mathcal{L}_{SM} + \ell\ \mathcal{C}_4 \ell \Delta$$





[CMS 1802.02965v2]

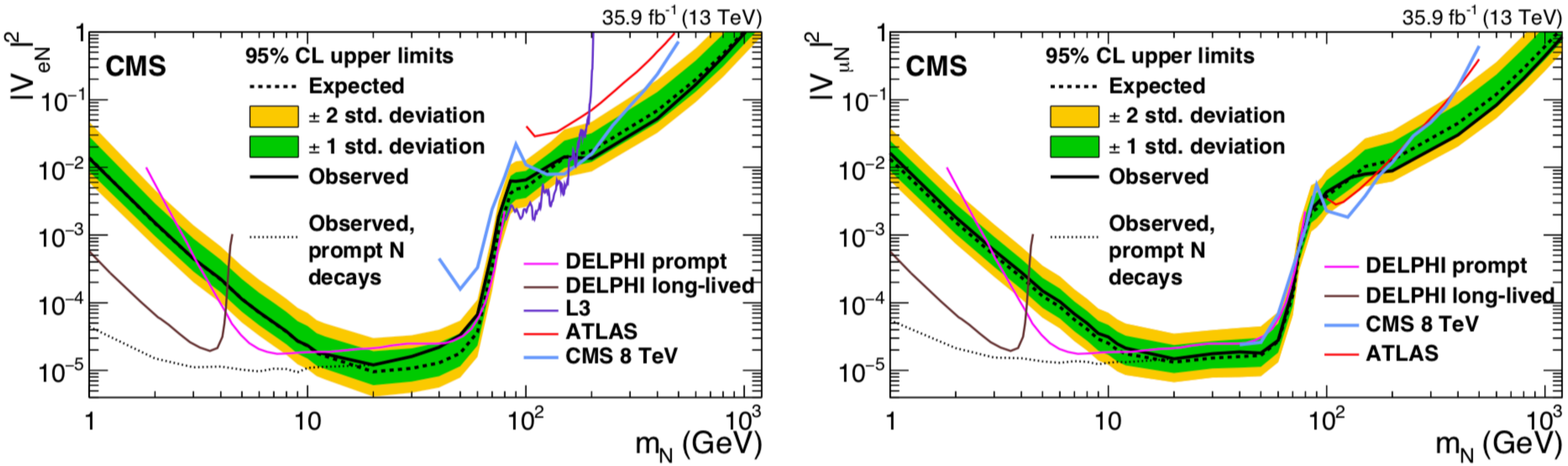


Figure 2: Exclusion region at 95% CL in the $|V_{\mathrm{eN}}|^2$ vs. m_{N} (left) and $|V_{\mu\mathrm{N}}|^2$ vs. m_{N} (right) planes. The dashed black curve is the expected upper limit, with one and two standard-deviation bands shown in dark green and light yellow, respectively. The solid black curve is the observed upper limit, while the dotted black curve is the observed limit in the approximation of prompt N decays. Also shown are the best upper limits at 95% CL from other collider searches in L3 [41], DELPHI [38], ATLAS [28], and CMS [27].

any relation to the muon (g-2) ?

- among all possible 1-particle extensions of the SM a special property enjoyed by scalar LQ that couples to quarks of BOTH chiralities

$S_1 = (\bar{3}, 1, +1/3)$ $\qquad$ $R_2 = (3,2,+7/6)$

[not automatically p-decay free]

- contributions to dipole transitions can be chirally enhanced

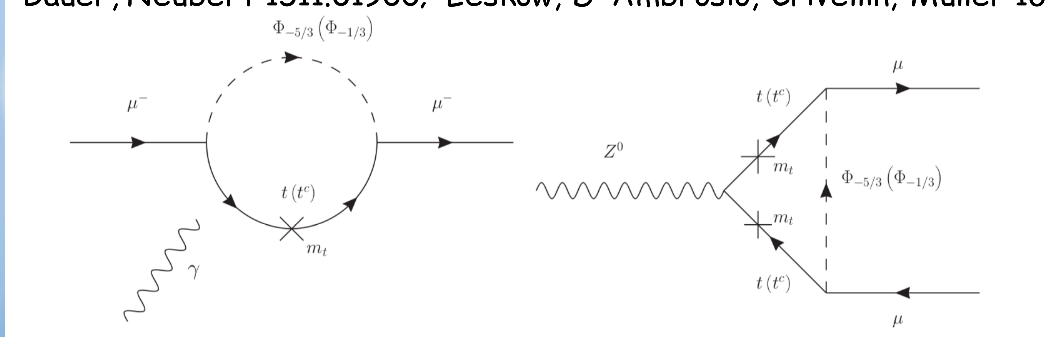
δa_ℓ	$\Gamma(\ell \to \ell' \gamma)$
$\frac{1}{16\pi^2} \frac{m_\ell m_{top}}{M_{LQ}^2} g_{t\ell}^L g_{t\ell}^R$	$\frac{\alpha_{em}}{256\pi^4} \frac{m_\ell^3 m_{top}^2}{M_{LQ}^4} \lvert g_{t\ell}^{L(R)} g_{t\ell'}^{R(L)} \rvert^2$

[Djouadi, Kohler, Spira, Tutas, 1990
Chakraverty, Choudhury, Datta 0102180
Cheung 0102238
Biggio, Bordone 1411.6799]

δa_μ of correct size for $M_{LQ} \approx 1$ TeV in a weak coupling regime

- 1-to-1 correlation to (chirally enhanced) deviations in Z-coupling to leptons

Bauer, Neubert 1511.01900; Leskow, D' Ambrosio, Crivellin, Muller 1612.06858]



$$\delta BR(Z \to \ell^+ \ell^-) \approx \frac{1}{16\pi^2} \frac{m_{top}^2}{M_{LQ}^2} \lvert g_{t\ell}^L \rvert^2$$

- many models addressing B-anomalies include S_1 or R_2 in their spectrum

[NC anomaly requires special care: no contribution to $b \to s\ell^+\ell^-$ from tree-level S_1 exchange; C_9=+C_{10} from R_2 exchange]

Bauer, Neubert 1511.01900	S_1
Chen, Nomura, Okada 160704857	$R_2 + S_3$
Caio, Gargalionis, Schmidt, Volkas 1704.05849	S_1
Becirevic, Sumensari, 1704.05835	R_2
Chauhan, Kindra,Narang, 1706.04598	R_2
Crivellin, Muller, Ota, 1703.09226	$S_1 + S_3$
…	

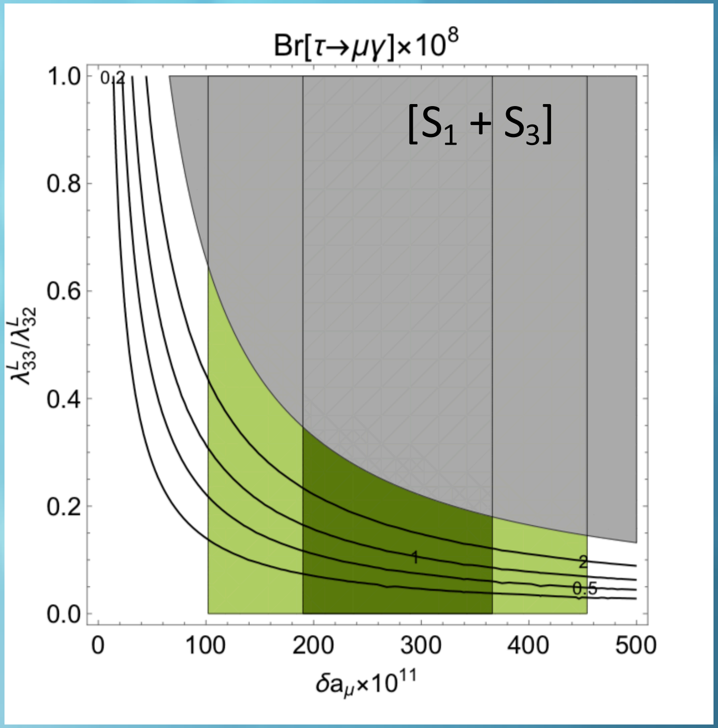
- if LQ couples mainly to top and 2nd lepton generation

$$\delta a_\mu \approx +3\times10^{-9} \Rightarrow \delta BR(Z \to \mu^+\mu^-) \approx 10^{-4}$$

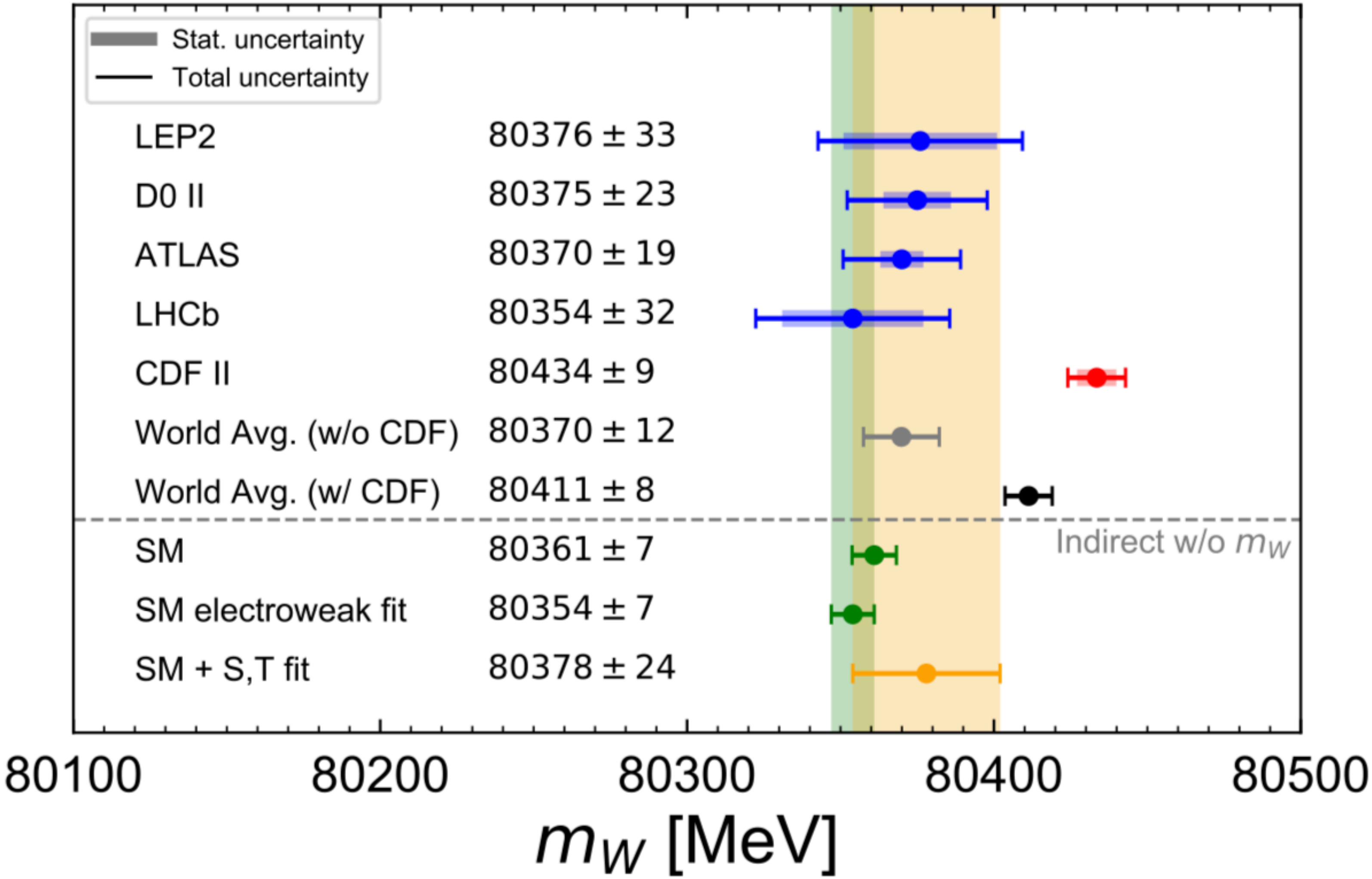
- If LQ couples also to top and 3rd lepton generation

$$\frac{BR(\tau \to \mu\gamma)}{(\delta a_\mu)^2} \geq \frac{9\times10^{-7}}{(+3\times10^{-9})^2}\left(\frac{g^L_{33}}{g^L_{32}}\right)^2$$

$$BR(Z \to \tau^\pm\mu^\mp) \approx \frac{10^{-8}(g^L_{33}g^L_{32})^2}{M^4_{LQ}(TeV)}$$



[Crivellin, Muller, Ota, 1703.09226]



[Emanuele Bagnaschi, John Ellis, Maeve Madigan, Ken Mimasu, Veronica Sanze, and Tevong You, 2204.05260v2]

tests of modulus couplings

G-J. Ding, FF, 2003.13448

non standard neutrino interactions

$$\mathcal{L} = i \sum_{f=e,e^c,\nu} \overline{f}\,\overline{\sigma}^\mu \partial_\mu f + \frac{1}{2}\partial_\mu \varphi_\alpha \partial^\mu \varphi_\alpha - \frac{1}{2} M_\alpha^2 \varphi_\alpha^2 - (m_e + \mathcal{Z}_\alpha^e \varphi_\alpha) e^c e - \frac{1}{2}\nu(m_\nu + \mathcal{Z}_\alpha^\nu \varphi_\alpha)\nu + h.c. + \ldots .$$

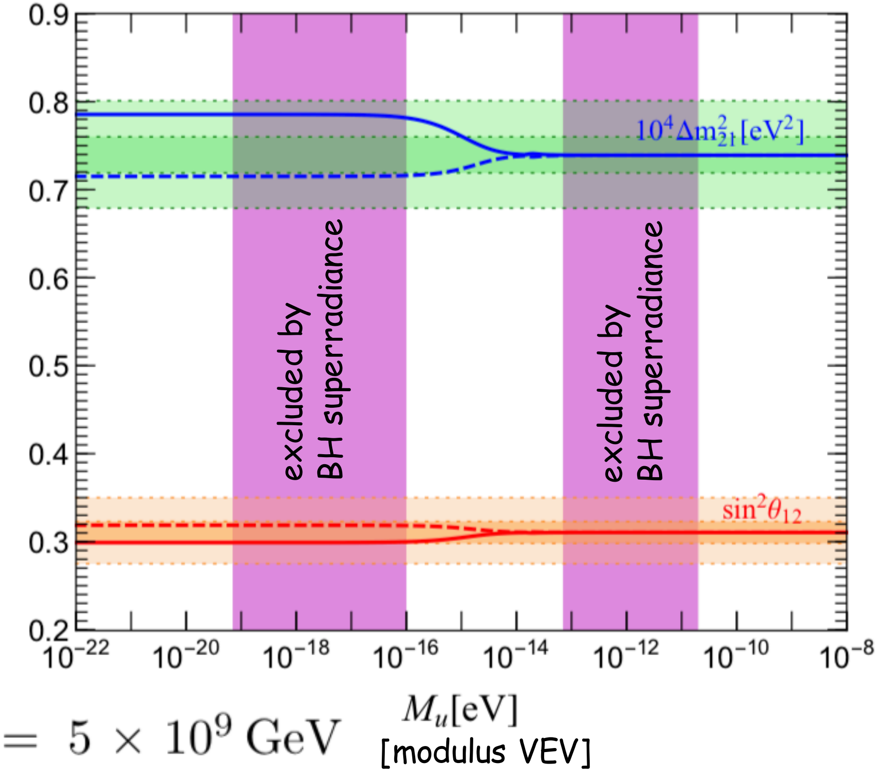
$$\tau = \langle \tau \rangle + \frac{\varphi_u + i\,\varphi_v}{\sqrt{2}}$$

in medium with non-zero electron number density

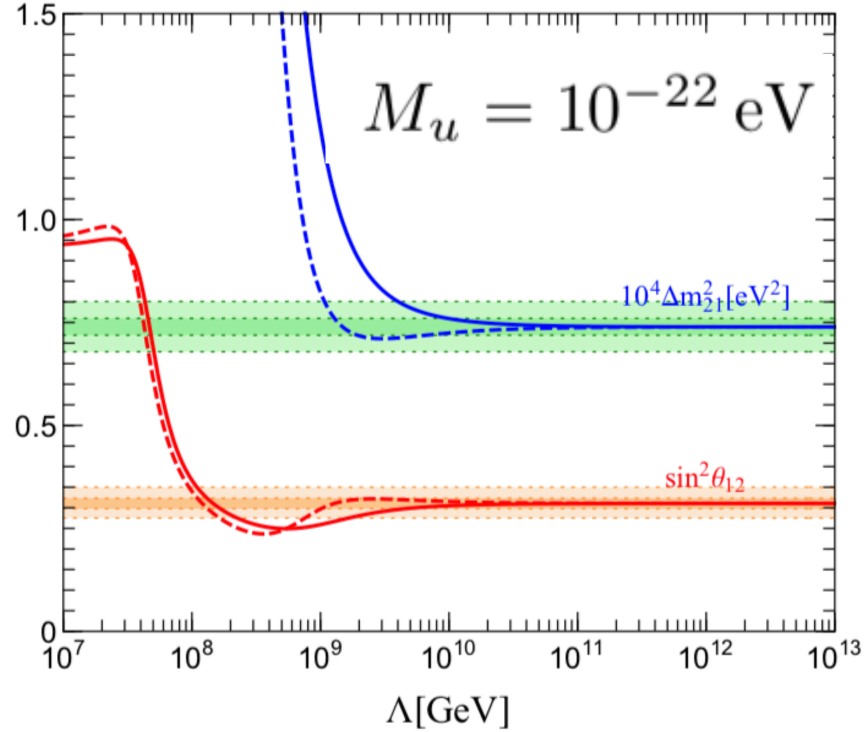
small, unless the modulus is very light

$$\delta m_\nu(0) = -n_e^0 \frac{\mathrm{Re}(\mathcal{Z}^e)\mathcal{Z}^\nu}{M^2(R)} ,$$

in the sun:



$\Lambda = 5 \times 10^9$ GeV



	"flavor+electroweak" $m >$ EW (2σ limit)	"Averaged-out oscillations" $\Delta m^2 \gtrsim 0.1$ eV^2 (90% CL)
α_{ee}	$1.3 \cdot 10^{-3}$ [36]	$8.4 \cdot 10^{-3}$ [55]
$\alpha_{\mu\mu}$	$2.2 \cdot 10^{-4}$ [36]	$5.0 \cdot 10^{-3}$ [15]
$\alpha_{\tau\tau}$	$2.8 \cdot 10^{-3}$ [36]	$6.5 \cdot 10^{-2}$ [56]
$\lvert\alpha_{\mu e}\rvert$	$6.8 \cdot 10^{-4}$ ($2.4 \cdot 10^{-5}$) [36]	$9.2 \cdot 10^{-3}$
$\lvert\alpha_{\tau e}\rvert$	$2.7 \cdot 10^{-3}$ [36]	$1.4 \cdot 10^{-2}$
$\lvert\alpha_{\tau\mu}\rvert$	$1.2 \cdot 10^{-3}$ [36]	$1.1 \cdot 10^{-2}$

Table 1: **Current upper bounds on the α parameters.** The bounds in the middle column (shown at 2σ, 1 d.o.f.) apply for $\Delta m^2 \gtrsim 100$ eV^2 and are taken to a global fit to flavor and electroweak precision observables from Ref. [36]. The bounds in the right column (shown at 90% CL, for 1 d.o.f.) apply for $\Delta m^2 \gtrsim 0.1$ eV^2 and come from neutrino oscillation searches, when the sterile neutrinos would be in the averaged-out regime for such a mass scale. The second number quoted in parenthesis for the $\alpha_{\mu e}$ element includes the $\mu \to e\gamma$ observable, which can in principle be evaded [28]. The bounds without a reference are indirectly obtained from constraints on the diagonal parameters via $\alpha_{\alpha\beta} \leq 2\sqrt{\alpha_{\alpha\alpha}\alpha_{\beta\beta}}$, which follows from the unitarity of the full $\mathcal{U}$ mixing matrix.

[Enrique Fernandez-Martinez, Josu Hernandez-Garcia, and Jacobo Lopez-Pavon 1605.08774v2]

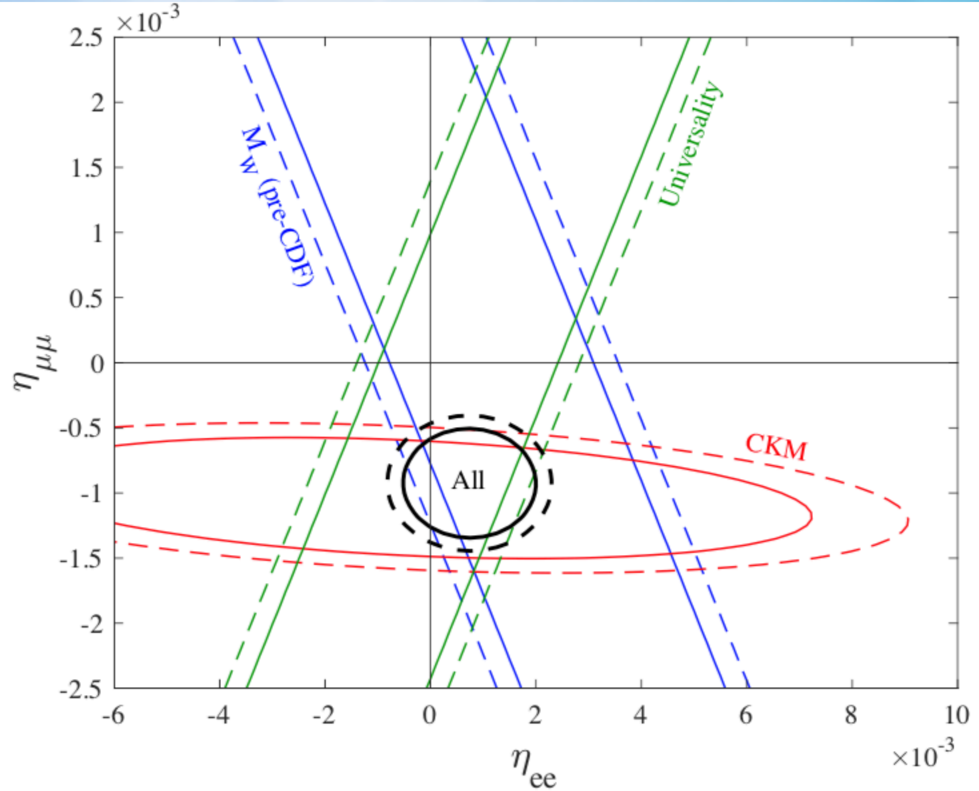


Figure 1. Results of our fit, projected onto the η_{ee}-$\eta_{\mu\mu}$-plane. The solid (dashed) curves correspond to the allowed regions at 95% CL (99% CL), for 2 d.o.f.. The constraints are labelled as 'M_W' for the measurement of the W mass, 'Universality' for the lepton flavour universality bounds, and 'CKM' for the bounds coming from beta and kaon decays. In the upper (lower) panel we take the constraints on M_W from CDF II [7] (the global average before CDF II [42]). The black contours correspond to combinations of different data sets, see text for details.