The classical Lagrangian of the Standard Model (SM) of particle physics features the global symmetry group $U(1)_B \times U(1)_{L_e} \times U(1)_{L_\mu} \times U(1)_{L_\tau}$ associated with the conservation of baryon number $B$ and the three lepton numbers $L_{e,\mu,\tau}$. Defining the total lepton number $L \equiv L_e + L_\mu + L_\tau$, this global symmetry group can also be written in the following basis,

$$U(1)_{B-L} \times U(1)_{B-L} \times U(1)_{L_\mu-L_e} \times U(1)_{L_\mu+L_\tau-2L_e}. \tag{1}$$

In principle this is useful because the linear combination $B+L$ is actually broken at the quantum level by non-perturbative processes by six units, specifically $\frac{1}{2} \Delta B = \Delta L_e = \Delta L_\mu = \Delta L_\tau = 1$. Neutrino oscillations have proven furthermore that lepton flavor, $U(1)_{L_\mu-L_e} \times U(1)_{L_\mu+L_\tau-2L_e}$, is not conserved in nature, leaving at most $U(1)_{B-L}$ as an unbroken symmetry.

Practically speaking, however, the $B+L$ violating processes are much too suppressed (at zero temperature) to ever be observable, and the same goes for charged-lepton flavor violation (CLFV) induced by non-zero neutrino masses $m_j$ and a non-trivial leptonic mixing matrix $U$. For example, Dirac neutrinos lead to $\Delta(L_\beta-L_\alpha)$ at two CLFV at the one-loop level,

$$\frac{\Gamma(\ell_\alpha \to \ell_\beta\gamma)}{\Gamma(\ell_\alpha \to \ell_\beta\nu_\alpha\nu_\beta)} \approx \frac{3\Omega_{\text{EM}}}{32\pi} \sum_{j=2,3} U_{\alpha j}^2 \frac{\Delta m^2_{21}}{M_W^2} U_{j3}^2,$$  

which is smaller than $10^{-53}$ for all channels and hence completely unobservable. The Glashow–Iliopoulos–Maiani mechanism ensures that all neutrino-induced CLFV processes are suppressed by the sub-eV$^2$ neutrino-mass-squared differences $\Delta m^2_{ij}$, because degenerate (Dirac) neutrino masses would render $U$ unphysical and thus reinstates lepton flavor symmetry.

As a result, the group of Eq. (1) is still an excellent approximate symmetry for charged leptons: the observation of CLFV would imply physics beyond the SM and beyond neutrino oscillations — with many models being able to saturate current limits (see e.g. Refs. [4, 5] for current reviews). Processes under experimental investigation are listed in Tabs. [1, 11], focusing on rare decays rather than collider signatures. The next decade will see significant improvement of these limits or even a discovery, with MEG-II, Mu3e, Mu2e, COMET and DeeMe probing $\mu \to e\gamma, 3e$ and $\mu \to e$ conversion; LHCb, BES-III and Belle-II probing CLFV decays of taus and hadrons; and the (HL-)LHC probing CLFV decays of the Brout–Englert–Higgs boson $h$ among other channels. (Limits on LFV $Z$ decays could be improved by many orders of magnitude at future $e^+e^-$ colliders, not listed in our tables.) It is thus timely to study how a possible discovery can be interpreted. In the following, we will make an effort to study CLFV model independently by focusing on the quantum numbers of the various processes.

**LEPTON FLAVOR VIOLATION**

Following standard convention, we define CLFV as processes that conserve total lepton number $L$ (and $B$) but violate $U(1)_{L_\mu-L_e} \times U(1)_{L_\mu+L_\tau-2L_e}$ and do not involve neutrinos. The decays in Tabs. [1, 11] have been sorted into (six) groups according to the lepton numbers that are violated; this already enables us to make model-independent qualitative predictions: if one process of a given group is observed, all processes of said group unavoidably exist, being at least generated at loop level. All processes of one group provide the same quantum-number information. The different branching ratios within each group are model dependent, as is the question of whether more than one group is observable. (The chiralities of the fermions involved in CLFV and the impact on lepton-flavor conserving observables such as $g-2$ [14] are also model dependent.)

It is indeed possible that only one of the groups in Tabs. [1, 11] is observable, i.e. only one linear combination of lepton flavors is violated, while the others are conserved (outside of the neutrino sector). A concrete model

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1. At present there is one tantalizing $\sim 2.5\sigma$ hint for CLFV in the channel $h \to \mu\tau + \tau\mu$ by CMS [6], yet to be confirmed or excluded by $\sqrt{s} = 13$ TeV data [7, 8] or ATLAS [9, 9].

2. This statement has to be modified if light new-physics modes such as $\ell_\alpha \to \ell_3Z^0$ [10, 11] are included in the list (or observed).
The above discussion is meant to illustrate the somewhat trivial point that the observation of one CLFV process only proves that one linear combination of lepton numbers is broken, while the other(s) might still be conserved. Using without loss of generality the basis of Eq. \(1\), the observation of one CLFV process means that \(U(1)_{L_{\mu} - L_{\tau}} \times U(1)_{L_{\tau} + L_{e} - 2L_{e}}\) is broken to a \(U(1)' \times Z_{N}\) subgroup. The observation of a second CLFV process (from a different group) implies that \(U(1)' \times Z_{N}\) is further broken down to

\[Z_{\Delta(L_{\mu} - L_{\tau})} \times Z_{\Delta(L_{e} + L_{\tau} - 2L_{e})},\]

which might contain some redundancies as we will see later (see also Ref. \(37\) on this topic). All CLFV processes can be conveniently drawn on this lattice, shown in Fig. \(3\) labeled by one representative process (e.g. \(\mu \rightarrow e\gamma\) stands for all \(\Delta(L_{e} - L_{\mu}) = 2\) processes from Tab. \(3\)). Here we included far more processes than listed in Tabs. \(3\) for the sake of illustration, even though many of them are not testable. In fact, the only realistically testable processes not already listed are \(\mu \rightarrow e\gamma\) (violating \(\Delta(L_{e} - L_{\mu}) = 4\), for which experimental limits from muonium exist \(35\), and \(\tau \rightarrow \mu e\mu \bar{e}\).

Simple vector addition now allows us to make model-independent interpretations of CLFV from Fig. \(3\). For example, the observation of \(\mu \rightarrow e\gamma = (-3, -1)\) and \(\tau \rightarrow \mu e\mu \bar{e} = (0, 2)\) implies that \(\tau \rightarrow e\gamma\) \((-3, 1)\) must exist, as well as in fact all other CLFV processes, because each point on the lattice can be written as \(n(-3, -1) + m(0, 2)\) with \(n, m \in Z\). Observing two different groups of Tab. \(3\) is thus sufficient to prove that all CLFV exist, i.e. that the flavor group \(U(1)_{L_{\mu} - L_{\tau}} \times U(1)_{L_{e} + L_{\tau} - 2L_{e}}\) is completely broken.\(^3\) It is of course impossible to make model-independent statements about the size and ratios of the different CLFV channels.

Two (orthogonal) CLFV processes are however not always enough to establish the full breakdown of the flavor group. For example, the observation of \(\tau \rightarrow \gamma\) \((0, 2)\) and \(\tau \rightarrow e\mu e\mu \bar{e} = (-6, 0)\) implies that a coarser sublattice is generated, which in particular does not include \(\mu \rightarrow e\gamma\) or \(\tau \rightarrow e\gamma\) (Fig. \(3\)). Formally, \(U(1)_{L_{\mu} - L_{\tau}} \times U(1)_{L_{e} + L_{\tau} - 2L_{e}}\) is broken to a \(Z_{3}\) subgroup

\[^3\text{From Fig. 3 it might seem like } U(1)_{L_{\mu} + L_{\tau} - 2L_{e}} \text{ always has an unbroken } Z_{3} \text{ subgroup under which } (\mu, \tau, e) \sim (1, 1, -2), \text{ but this is actually a } U(1)\text{ subgroup because } (1, 1, -2) \sim (1, 1, 1) \text{ mod } 3, \text{ which can hence be ignored.}\]
neutral states (corresponding to \( \pi \) to the meson octet, where we of course neglect the two flavor symmetry according to their transformation properties under the (approximate) flavor symmetry). We are effectively organizing processes such as \( \ell \to \alpha \) to a meson octet as a result of \( SU(3) \) breaking. For the convenience of the reader, we provide a simple flowchart of possible CLFV in Tab. III, assuming only \( \Delta(\alpha + \alpha - 2L_e) = 6 \) and \( \Delta(\alpha - \alpha) = 2 \) (3). The latter is a way to organize processes such as \( \ell \to \gamma \) and \( ee \to \gamma \), implied by the 

\[
\begin{array}{c|c|c}
\text{Observation of charged lepton flavor violation} & \Rightarrow & \text{Remaining symmetry} \\
\hline
\Delta(L_\alpha - L_\beta) = 2 & U(1)_{L_\alpha + L_\beta - 2L_e} \\
\Delta(L_\alpha + L_\beta - 2L_e) = 6 & U(1)_{L_\alpha - L_\beta} \\
\Delta(L_\alpha + L_\beta - 2L_\gamma) = 6 & Z_2: \ell_\alpha \to -\ell_\gamma \\
\Delta(L_\alpha + L_\beta - 2L_\gamma) = 6 & Z_3: (\ell_\alpha, \ell_\beta, \ell_\gamma) \sim (0, 1, 2) \\
\Delta(L_\alpha - L_\beta) = 2 & Z_2: \ell_\alpha \to -\ell_\gamma \\
\Delta(L_\alpha - L_\beta) = 2 & Z_3: (\ell_\alpha, \ell_\beta, \ell_\gamma) \sim (0, 1, 2) \\
\end{array}
\]

FIG. 1: CLFV processes (only one representative shown per group) organized by their \( U(1)_{L_\alpha - L_\beta \times U(1)_{L_\mu + L_\tau - 2L_e}} \) breaking.

TABLE III: Observation of CLFV \( (U(1)_{L_\mu - L_\tau} \times U(1)_{L_\mu + L_\tau - 2L_e}) \) breaking via processes of Tabs. I and remaining subgroups after up to two CLFV discoveries. Three observations – at least one from each table – imply full flavor breakdown.

Let us make one final remark about the similarity of Fig. 1 with the well-known hadron multiplets of Gell-Mann’s Eightfold Way. The latter is a way to organize \( q \bar{q} \) (and \( qqq \)) states according to their transformation properties under the (approximate) flavor symmetry \( SU(3)_f \) with \( q = (u, d, s) \sim 3 \), leading in particular to a meson octet as a result of \( 8 \subset 3 \otimes 3 \). In Fig. 1 we are effectively organizing processes such as \( \ell \to \ell(\ell \ell) \) according to their transformation properties under the flavor symmetry \( SU(3)_f \) with \( \ell = (e, \mu, \tau) \sim 3 \). The \( \ell_\alpha \to \ell_\beta \gamma \) processes then form a LFV “octet” similar to the meson octet, where we of course neglect the two neutral states (corresponding to \( \pi^0 \) and \( \eta \)) that do not violate flavor. Similarly, the 12 processes \( \ell \to \ell(\ell \ell) \), e.g. \( \tau \to \mu \mu e \) and \( ee \to \gamma \), can be seen as part of the \( 27 \subset 3 \otimes 3 \otimes 3 \), which again includes many singlets not of interest for LFV. Baryon multiplets do not have an analogue in LFV because angular momentum and the assumed baryon number conservation forbid processes such as \( \ell \to \ell \ell \) that would correspond to \( 3 \otimes 3 \otimes 3 \). We stress that the similarity of Fig. 1 with the meson multiplets is purely formal; \( SU(3)_f \) is broken badly by the different lepton masses, leaving only the abelian Cartan subgroup \( U(1)_{L_\alpha - L_\beta \times U(1)_{L_\mu + L_\tau - 2L_e}} \) as a possible symmetry of nature, which is thus a better starting point for LFV.

**LEPTON NUMBER VIOLATION**

For the study of CLFV we assumed \( L \) and \( B \) to be conserved, which is a convenient simplification – allowing us to represent CLFV in a two-dimensional plane (Fig. 1) – and could well be true if neutrinos are Dirac particles and \( B - L \) is unbroken [2]. Let us loosen this assumption and allow for lepton number violation (LNV), still keeping \( B \) conserved for simplicity. Even though our decomposition
of Eq. (1) suggests LFV (as defined above) and LNV to be unrelated issues, all currently probed LNV processes (Tab. IV) in fact violate lepton flavor. True LNV, conserving flavor and baryon number, is a lot harder to come by and involves at least six leptons—e.g., \( e\bar{e} \rightarrow \mu\bar{\mu}\tau\bar{\tau} \) plus charged bosons—because all known fermions carry flavor or baryon number.\(^4\) As such, any observation of LNV is practically also an observation of LFV. We list possible LNV processes in Tab. IV, focusing again on decays rather than collider signatures. We urge experimentalists to complete Tab. IV by looking for meson decays into \( \tau^+\ell^- \), e.g., \( B^+ \rightarrow \tau^-\ell^+ \), with \( \ell \in \{e, \mu, \tau\} \).\(^10\)

Similar to CLFV we only list LNV by a few units because experimental signatures of \( \Delta L > 2 \) are much more challenging\(^11,12\). (A first preliminary limit on \( \Delta L_n = 4 \) was presented recently by NEMO-3 in the form of a lower limit of \( 2.6 \times 10^{21} \text{ yr} \) on the neutrinoless quadruple beta decay\(^11,15\)).

Of the processes in Tab. IV neutrinoless double beta decay \( 0\nu\beta\beta \) is the only one that is sensitive to neutrino-induced LNV/LFV. Since we already know from neutrino oscillations that lepton flavor is broken, the observation of \( 0\nu\beta\beta \) would prove that all three lepton numbers \( L_{e,\mu,\tau} \) are broken in the neutrino sector. This implies in particular that neutrinos are Majorana particles\(^21\) and the existence of additional particles such as scalars or heavier Majorana partners as a UV completion of the Weinberg operator\(^22\) but is not sufficient to tell us anything about charged lepton flavor.

An observation of a process from Tab. IV other than \( 0\nu\beta\beta \) would on the other hand imply that lepton flavor is definitely broken in the charged-lepton sector,

\[
U(1)_{L_e} \times U(1)_{L_{\mu}} \times U(1)_{L_{\tau}} \rightarrow U(1) \times U(1)^\prime \times \mathbb{Z}_N. \tag{6}
\]

For example, the discovery of \( \Delta(L_{\alpha} + L_{\beta}) = 2 \) would imply that \( U(1)_{L_e} \times U(1)_{L_{\mu}} \times U(1)_{L_{\tau}} \) could still be a good symmetry for charged leptons, making necessary further CLFV or LNV observations to establish full flavor breaking (a grid similar to Fig. I but with axes \( L_{\mu} \) and \( L_{\alpha} - L_{\beta} \) can be drawn to make model-independent studies). It is straightforward but tedious and not particularly illuminating to extend the flowchart of Tab. III to LNV. (The processes in Tab. IV were also studied in connection to the Majorana neutrino mass matrix in Ref.\(^{53} \)). Baryon number violation of course adds yet another dimension to the parameter space and can be explored completely analogously.

**CONCLUSION**

In summary, the observation of CLFV implies a breakdown of the approximate global flavor symmetry group \( U(1)_{L_e} \times U(1)_{L_{\mu}} \times U(1)_{L_{\tau}} \) in the charged-lepton sector. If one process is observed, one linear combination of \( L_{\mu} - L_\tau \) and \( L_{\mu} + L_\tau - 2L_e \) is broken, while the orthogonal one might still be conserved (up to tiny neutrino-mediated contributions). Depending on the process, this could imply the existence of other testable CLFV channels (Tab. I), but could also be an isolated process (Tab. II). If two (orthogonal) CLFV processes are observed, Fig. I can be used to predict additional processes, which might not necessarily be all possible ones due to a possible remaining discrete subgroup. CLFV is hence far more than a yes–no question, with up to three qualitatively different discoveries required to establish that no flavor symmetry exists in the charged-lepton sector. The discovery of lepton number violation would practically imply lepton flavor violation as well and thus has to be taken into account when interpreting data. With a large number of experiments exploring untested parameter space, it is entirely possible that we see one or more discoveries within the next decade.

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\(^{4}\) Lorentz-invariant operators that conserve \( B \) but break \( L \) take the form \( \Theta^{\alpha} \) times bosonic fields, where \( n \in \mathbb{N} \). Since \( \ell = 3 \) under the \( SU(3)_\ell \) flavor group, \( n = 3 \) is the lowest-dimensional operator that contains flavor singlets, seeing as \( 3^6 \cong 1 \).

\(^{1}\) G. ’t Hooft, “Symmetry Breaking Through Bell–Jackiw Anomalies,” Phys. Rev. Lett. 37 (1976) 8–11.

\(^{2}\) J. Heck, “Unbroken \( B \sim L \) symmetry,” Phys. Lett. B739 (2014) 256–262. arXiv:1408.6845

\(^{*}\) Electronic address: Julian.Hечк@ulb.ac.be
[3] S. T. Petcov, “The Processes $\mu \to e\gamma$, $\mu \to eee$, $\nu' \to \nu'\gamma$ in the Weinberg-Salam Model with Neutrino Mixing,” Sov. J. Nucl. Phys. 25 (1977) 340. [Erratum: Yad. Fiz. 25, 1336 (1977)].

[4] A. de Gouvêa and P. Vogel, “Lepton Flavor and Number Conservation, and Physics Beyond the Standard Model,” Prog. Part. Nucl. Phys. 71 (2013) 75–92. arXiv:1303.4097

[5] R. H. Bernstein and P. S. Cooper, “Charged Lepton Flavor Violation: An Experimenters’s Guide,” Phys. Rept. 532 (2013) 27–64. arXiv:1307.5787.

[6] CMS, V. Khachatryan et al., “Search for Lepton-Flavour-Violating Decays of the Higgs Boson,” Phys. Lett. B749 (2015) 357–362. arXiv:1502.07400

[7] CMS, “Search for Lepton Flavour Violating Decays of the Higgs Boson in the mu-tau final state at 13 TeV.” CMS-PAS-HIG-16-005, 2016.

[8] ATLAS, G. Aad et al., “Search for lepton-flavour-violating $H \to \ell\ell$ decays of the Higgs boson with the ATLAS detector,” JHEP 11 (2015) 211. arXiv:1508.03372

[9] ATLAS, G. Aad et al., “Search for lepton-flavour-violating decays of the Higgs and Z bosons with the ATLAS detector,” arXiv:1604.07730

[10] R. Foot, X. He, H. Lew, and R. Volkas, “Model for a light $Z'$ boson,” Phys. Rev. D50 (1994) 4571–4580. arXiv:hep-ph/9401250.

[11] J. Heeck, “Lepton flavor violation with light vector bosons,” Phys. Lett. B758 (2016) 101–105. arXiv:1602.03810.

[12] W. Altmannshofer, C.-Y. Chen, P. S. B. Dev, and A. Soni, “Lepton flavor violation $Z'$ explanation of the muon anomalous magnetic moment,” Phys. Lett. B762 (2016) 389–398. arXiv:1607.06832.

[13] S. Davidson, “Learning about flavour structure from $\tau \to e\gamma$ and $\mu \to e\gamma$?,” Eur. Phys. J. C72 (2012) 1897. arXiv:1112.2956.

[14] M. Lindner, M. Platscher, and F. S. Queiroz, “A Call for New Physics: The Muon Anomalous Magnetic Moment and Lepton Flavor Violation,” arXiv:1610.06587.

[15] MEG, A. M. Baldini et al., “Search for the lepton flavour violating decay $\mu^+ \to e^+\gamma$ with the full dataset of the MEG experiment,” Eur. Phys. J. C76 (2016) no. 8, 434. arXiv:1605.05081.

[16] A. M. Baldini et al., “MEG Upgrade Proposal,” arXiv:1301.7225.

[17] SINDRUM, U. Bellgardt et al., “Search for the Decay $\mu^+ \to e^-e^-e^-$,” Nucl. Phys. B299 (1988) 1.

[18] A. Blondel et al., “Research Proposal for an Experiment to Search for the Decay $\mu \to eee$,” arXiv:1301.6113.

[19] SINDRUM II, W. H. Bertl et al., “A Search for muon to electron conversion in muonic gold,” Eur. Phys. J. C47 (2006) 337–346.

[20] COMET, Y. Kuno, “A search for muon-to-electron conversion at J-PARC: The COMET experiment,” PTEP 2013 (2013) 022C01.

[21] Mu2e, L. Bartoszek et al., “Mu2e Technical Design Report,” arXiv:1501.05241.

[22] CMS, V. Khachatryan et al., “Search for lepton flavour violating decays of the Higgs boson to $e\tau$ and $\mu\tau$ in proton-proton collisions at $\sqrt{s} = 8$ TeV.” Phys. Lett. B769 (2016) 336–340. arXiv:1607.03561.

[23] S. Banerjee, B. Bhattacharjee, M. Mitra, and M. Spannowsky, “The Lepton Flavour Violating Higgs Decays at the HL-LHC and the ILC,” JHEP 07 (2016) 050. arXiv:1603.05952.

[24] ATLAS, G. Aad et al., “Search for the lepton flavor violating decay $Z \to e\mu$ in $pp$ collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector,” Phys. Rev. D90 (2014) 072010. arXiv:1408.5774.

[25] BNL, D. Ambrose et al., “New limit on muon and electron lepton number violation from $K^0_L \to \mu^+e^-$ decay,” Phys. Rev. Lett. 81 (1998) 5734–5737. arXiv:hep-ex/9811038.

[26] NA62, M. Mouls, “Forbidden Kaon and Pion Decays in NA62,” PoS KAO113 (2013) 013, arXiv:1306.3383.

[27] BaBar Collaboration, B. Aubert et al., “Searches for Lepton Flavor Violation in the Decays $\tau \to e\gamma$ and $\tau \to \mu\gamma$,” Phys. Rev. Lett. 104 (2010) 021802. arXiv:0908.2281.

[28] T. Aushev, W. Bartel, A. Bondar, J. Brodzicka, T. Browder, et al., “Physics at Super B Factory,” arXiv:1002.5012.

[29] K. Hayasaka et al., “Search for Lepton Flavor Violating Tau Decays into Three Leptons with 719 Million Produced $\tau^+\tau^-$ Pairs,” Phys. Lett. B687 (2010) 139–143. arXiv:1001.3221.

[30] K. A. Olive, “Review of Particle Physics,” Chin. Phys. C40 (2016) no. 10, 100001.

[31] OPAL, R. Aker et al., “A Search for lepton flavour violating $Z'$ decays,” Z. Phys. C67 (1995) 555–564.

[32] BES, M. Ablikim et al., “Search for the lepton flavor violation processes $J/\psi \to \mu\tau$ and $e\tau$,” Phys. Lett. B598 (2004) 172–177. arXiv:hep-ex/0406018.

[33] Babar, J. P. Lees et al., “Search for Charged Lepton Flavor Violation in Narrow Upsilon Decays,” Phys. Rev. Lett. 104 (2010) 151802. arXiv:1001.1883.

[34] DELPHI, P. Abreu et al., “Search for lepton flavor number violating $Z'$ decays,” Z. Phys. C73 (1997) 243–251.

[35] J. Heeck, M. Holthausen, W. Rodejohann, and Y. Shimizu, “Higgs $\rightarrow \mu\mu$ in Abelian and Non-Abelian Flavour Symmetry Models,” Nucl. Phys. B896 (2015) 201–310. arXiv:1412.3671.

[36] K. S. Babu and C. E.ifestyles of the Majorana Neutrino Masses,” Phys. Lett. B203 (1988) 132–136.

[37] T. Browder, M. Rath, and R. Schieren, “Patterns of remnant discrete symmetries,” JHEP 08 (2009) 111. arXiv:0907.4049.

[38] L. Willmann et al., “New bounds from searching for muonium to anti-muonium conversion,” Phys. Rev. Lett. 82 (1999) 49–52. arXiv:hep-ex/9807011.

[39] M. Gell-Mann and Y. Ne’eman, “The Eightfold Way” Frontiers in Physics. Benjamin, New York, NY, 1964.

[40] K. Zuber, “Lepton Flavor and Lepton Number Violation with and without $\nu\bar{\nu}$ Production,” PoS LEP10 (2010) 201. arXiv:1008.3366.

[41] J. Heeck and W. Rodejohann, “Neutrinoless Quadruple Beta Decay,” Europhys. Lett. 103 (2013) 32001. arXiv:1306.0580.

[42] J. Heeck, “Lepton Number Violation with and without Majorana Neutrinos,” in Proceedings, 50th Rencontres de Moriond Electroweak Interactions and Unified Theories: La Thuile, Italy, March 14-21, 2015, pp. 309–316. 2015. arXiv:1503.07708.

[43] D. Waters, “Latest Results from NEMO-3 & Status of the SuperNEMO Experiment,” Talk at Neutrino 2016 Conference, London, 2016.
[44] S. Dell’Oro, S. Marcocci, M. Viel, and F. Vissani, “Neutrinoless double beta decay: 2015 review,” Adv. High Energy Phys. 2016 (2016) 2162659, arXiv:1601.07512.

[45] R. Appel et al., “Search for lepton flavor violation in K+ decays,” Phys. Rev. Lett. 85 (2000) 2877–2880, arXiv:hep-ex/0006003.

[46] NA48/2, K. Massri, “Searches for Lepton Number Violation and resonances in the K± → πµµ decays at the NA48/2 experiment,” in 51st Rencontres de Moriond on EW Interactions and Unified Theories La Thuile, Italy, March 12-19, 2016, 2016. arXiv:1607.04216.

[47] SINDRUM II, J. Kaulard et al., “Improved limit on the branching ratio of µ− → e+ conversion on titanium,” Phys. Lett. B422 (1998) 334–338.

[48] T. Geib, A. Merle, and K. Zuber, “µ−→ e+ conversion in upcoming LFV experiments,” Phys. Lett. B764 (2017) 157–162, arXiv:1609.09088.

[49] Belle, Y. Miyazaki et al., “Search for Lepton-Flavor-Violating and Lepton-Number-Violating τ → ℓνν’ Decay Modes,” Phys. Lett. B719 (2013) 346–351, arXiv:1206.5595.

[50] W. Rodejohann, “Neutrino-less Double Beta Decay and Particle Physics,” Int. J. Mod. Phys. E20 (2011) 1833–1930, arXiv:1106.1334.

[51] J. Schechter and J. W. F. Valle, “Neutrinoless Double beta Decay in SU(2) × U(1) Theories,” Phys. Rev. D25 (1982) 2951.

[52] S. Weinberg, “Baryon and Lepton Nonconserving Processes,” Phys. Rev. Lett. 43 (1979) 1566–1570.

[53] M. Hirsch, S. Kovalenko, and I. Schmidt, “Extended black box theorem for lepton number and flavor violating processes,” Phys. Lett. B642 (2006) 106–110, arXiv:hep-ph/0608207.