References

[1] R.L. Workman *et al.* (Particle Data Group), “Review of Particle Physics,” *Prog. Theor. Exp. Phys.* **2022**, 083C01 (2022). DOI: 10.1093/ptep/ptac097.

[2] S. Weinberg, Trans. New York Acad. Sci. **38** (1977), 185-201 doi:10.1111/j.2164-0947.1977.tb02958.x

[3] S. Raby, [arXiv:hep-ph/9501349 [hep-ph]].

[4] R. D. Peccei, AIP Conf. Proc. **424** (1998) no.1, 354-364 doi:10.1063/1.55128 [arXiv:hep-ph/9712422 [hep-ph]].

[5] H. Fritzsch and Z. z. Xing, Prog. Part. Nucl. Phys. **45** (2000), 1-81 doi:10.1016/S0146-6410(00)00102-2 [arXiv:hep-ph/9912358 [hep-ph]].

[6] Z. z. Xing, Int. J. Mod. Phys. A **29** (2014), 1430067 doi:10.1142/S0217751X14300671 [arXiv:1411.2713 [hep-ph]].

[7] F. Feruglio, Eur. Phys. J. C **75** (2015) no.8, 373 doi:10.1140/epjc/s10052-015-3576-5 [arXiv:1503.04071 [hep-ph]].

[8] N. Cabibbo and G. De Franceschi. Proc. VIIIth Nobel Symposium on Elementary particle theory, Aspenăsgården. May 1968.

[9] R. Gatto, G. Sartori and M. Tonin, Phys. Lett. B **28** (1968), 128-130 doi:10.1016/0370-2693(68)90150-0

[10] N. Cabibbo and L. Maiani, Phys. Lett. B **28** (1968), 131-135 doi:10.1016/0370-2693(68)90151-2

[11] R. J. Oakes, Phys. Lett. B **29** (1969), 683-685 doi:10.1016/0370-2693(69)90110-5

[12] N. Cabibbo and L. Maiani, Phys. Rev. D **1** (1970), 707-718 doi:10.1103/PhysRevD.1.707

[13] G. Abbas, Int. J. Mod. Phys. A **36**, 2150090 (2021) doi:10.1142/S0217751X21500901 [arXiv:1807.05683 [hep-ph]].

[14] G. Abbas, V. Singh, N. Singh and R. Sain, Eur. Phys. J. C **83**, no.4, 305 (2023) doi:10.1140/epjc/s10052-023-11471-5 [arXiv:2208.03733 [hep-ph]].

[15] G. Abbas, R. Adhikari and E. J. Chun, Phys. Rev. D **108** (2023) no.11, 115035 doi:10.1103/PhysRevD.108.115035 [arXiv:2303.10125 [hep-ph]].

[16] G. Abbas, A. K. Alok, N. R. S. Chundawat, N. Khan and N. Singh, Phys. Rev. D **110** (2024) no.11, 115015 doi:10.1103/PhysRevD.110.115015 [arXiv:2407.09255 [hep-ph]].

[17] A. Abada *et al.* [FCC], Eur. Phys. J. ST **228**, no.5, 1109-1382 (2019) doi:10.1140/epjst/e2019-900088-6

[18] A. Abada *et al.* [FCC], Eur. Phys. J. C **79**, no.6, 474 (2019) doi:10.1140/epjc/s10052-019-6904-3

[19] A. Crivellin and B. Mellado, Nature Rev. Phys. **6**, no.5, 294-309 (2024) doi:10.1038/s42254-024-00703-6 [arXiv:2309.03870 [hep-ph]].

[20] G. Aad *et al.* [ATLAS], [arXiv:2405.04914 [hep-ex]].

[21] M. Battaglieri, B. J. Briscoe, A. Celentano, S. U. Chung, M. L. L. da Silva, A. D'Angelo, R. De Vita, M. Döring, J. Dudek and S. Eidelman, *et al.* Acta Phys. Polon. B **46** (2015), 257 doi:10.5506/APhysPolB.46.257 [arXiv:1412.6393 [hep-ph]].

[22] G. Abbas, "Solving the fermionic mass hierarchy of the standard model," Int. J. Mod. Phys. A **34**, no. 20, 1950104 (2019) doi:10.1142/S0217751X19501045 [arXiv:1712.08052 [hep-ph]].

[23] G. Abbas, "The standard HVM," [arXiv:2310.12915 [hep-ph]]. To be published in Mod.Phys.Lett.A

[24] G. Abbas, "Origin of the VEVs hierarchy," Int. J. Mod. Phys. A **37** (2022) no.11n12, 2250056 doi:10.1142/S0217751X22500567 [arXiv:2012.11283 [hep-ph]].

[25] G. Abbas and N. Singh, "Dark-technicolour at low scale," [arXiv:2312.16532 [hep-ph]].

[26] G. Abbas and N. Singh, [arXiv:2412.08523 [hep-ph]].

[27] S. Weinberg, Phys. Rev. D **5**, 1962-1967 (1972) doi:10.1103/PhysRevD.5.1962

[28] Model physicist, 13 October 2017, Matthew Chalmers, CERN, https://cerncourier.com/a/model-physicist/

[29] S. Weinberg, Phys. Rev. Lett. **29** (1972), 388-392 doi:10.1103/PhysRevLett.29.388

[30] H. Georgi and S. L. Glashow, Phys. Rev. D **6** (1972), 2977-2982 doi:10.1103/PhysRevD.6.2977

[31] H. Georgi and S. L. Glashow, Phys. Rev. D **7**, 2457-2463 (1973) doi:10.1103/PhysRevD.7.2457

[32] C. D. Froggatt and H. B. Nielsen, Nucl. Phys. B **147**, 277 (1979). doi:10.1016/0550-3213(79)90316-X

[33] M. Leurer, Y. Nir and N. Seiberg, Nucl. Phys. B **398**, 319 (1993); M. Leurer, Y. Nir and N. Seiberg, Nucl. Phys. B **420**, 468 (1994).

[34] E. J. Chun and A. Lukas, Phys. Lett. B **387**, 99-106 (1996) doi:10.1016/0370-2693(96)01015-5 [arXiv:hep-ph/9605377 [hep-ph]].

[35] K. S. Babu and S. Nandi, Phys. Rev. D **62**, 033002 (2000) doi:10.1103/PhysRevD.62.033002 [hep-ph/9907213].

[36] G. G. Ross and L. Velasco-Sevilla, Nucl. Phys. B **653**, 3-26 (2003) doi:10.1016/S0550-3213(03)00041-5 [arXiv:hep-ph/0208218 [hep-ph]]. S. F. King, JHEP **01**, 119 (2014) doi:10.1007/JHEP01(2014)119 [arXiv:1311.3295 [hep-ph]]. G. F. Giudice and O. Lebedev, Phys. Lett. B **665**, 79-85 (2008) doi:10.1016/j.physletb.2008.05.062 [arXiv:0804.1753 [hep-ph]].

[37] A. Davidson, V. P. Nair and K. C. Wali, Phys. Rev. D **29**, 1504 (1984) doi:10.1103/PhysRevD.29.1504

[38] A. Davidson and K. C. Wali, Phys. Rev. Lett. **60**, 1813 (1988) doi:10.1103/PhysRevLett.60.1813

[39] Z. G. Berezhiani and M. Y. Khlopov, Sov. J. Nucl. Phys. **51**, 739-746 (1990)

[40] Z. G. Berezhiani and M. Y. Khlopov, Sov. J. Nucl. Phys. **51**, 935-942 (1990)

[41] Z. G. Berezhiani and M. Y. Khlopov, Z. Phys. C **49**, 73-78 (1991) doi:10.1007/BF01570798

[42] A. S. Sakharov and M. Y. Khlopov, Phys. Atom. Nucl. **57**, 651-658 (1994)

[43] A. Hinata, JHEP **07**, 147 (2020) doi:10.1007/JHEP07(2020)147 [arXiv:2004.08824 [hep-ph]].

[44] T. Higaki and J. Kawamura, JHEP **03**, 129 (2020) doi:10.1007/JHEP03(2020)129 [arXiv:1911.09127 [hep-ph]].

[45] G. Abbas, doi:10.31526/ACP.BSM-2023.3 [arXiv:2404.03232 [hep-ph]].

[46] H. Georgi and A. Pais, Phys. Rev. D **10** (1974), 539 doi:10.1103/PhysRevD.10.539

[47] A. De Rujula, H. Georgi and S. L. Glashow, Annals Phys. **109** (1977), 258 doi:10.1016/0003-4916(77)90172-5

[48] H. Fritzsch, Phys. Lett. B **70** (1977), 436-440 doi:10.1016/0370-2693(77)90408-7

[49] F. Wilczek and A. Zee, Phys. Rev. Lett. **42** (1979), 421 doi:10.1103/PhysRevLett.42.421

[50] M. Leurer, Y. Nir and N. Seiberg, Nucl. Phys. B **398** (1993), 319-342 doi:10.1016/0550-3213(93)90112-3 [arXiv:hep-ph/9212278 [hep-ph]].

[51] M. Leurer, Y. Nir and N. Seiberg, Nucl. Phys. B **420** (1994), 468-504 doi:10.1016/0550-3213(94)90074-4 [arXiv:hep-ph/9310320 [hep-ph]].

[52] L. E. Ibanez and G. G. Ross, Phys. Lett. B **332** (1994), 100-110 doi:10.1016/0370-2693(94)90865-6 [arXiv:hep-ph/9403338 [hep-ph]].

[53] P. Binetruy and P. Ramond, Phys. Lett. B **350** (1995), 49-57 doi:10.1016/0370-2693(95)00297-X [arXiv:hep-ph/9412385 [hep-ph]].

[54] E. Dudas, S. Pokorski and C. A. Savoy, Phys. Lett. B **356** (1995), 45-55 doi:10.1016/0370-2693(95)00795-M [arXiv:hep-ph/9504292 [hep-ph]].

[55] Y. Grossman and Y. Nir, Nucl. Phys. B **448** (1995), 30-50 doi:10.1016/0550-3213(95)00203-5 [arXiv:hep-ph/9502418 [hep-ph]].

[56] Y. Nir, Phys. Lett. B **354** (1995), 107-110 doi:10.1016/0370-2693(95)00619-V [arXiv:hep-ph/9504312 [hep-ph]].

[57] R. Barbieri, G. R. Dvali and L. J. Hall, Phys. Lett. B **377** (1996), 76-82 doi:10.1016/0370-2693(96)00318-8 [arXiv:hep-ph/9512388 [hep-ph]].

[58] P. Binetruy, S. Lavignac and P. Ramond, Nucl. Phys. B **477** (1996), 353-377 doi:10.1016/0550-3213(96)00296-9 [arXiv:hep-ph/9601243 [hep-ph]].

[59] R. Barbieri, L. J. Hall, S. Raby and A. Romanino, Nucl. Phys. B **493** (1997), 3-26 doi:10.1016/S0550-3213(97)00134-X [arXiv:hep-ph/9610449 [hep-ph]].

[60] K. Choi, E. J. Chun and H. D. Kim, Phys. Lett. B **394** (1997), 89-98 doi:10.1016/S0370-2693(96)01674-7 [arXiv:hep-ph/9611293 [hep-ph]].

[61] A. E. Nelson and D. Wright, Phys. Rev. D **56** (1997), 1598-1604 doi:10.1103/PhysRevD.56.1598 [arXiv:hep-ph/9702359 [hep-ph]].

[62] W. Buchmuller and T. Yanagida, Phys. Lett. B **445** (1999), 399-402 doi:10.1016/S0370-2693(98)01480-4 [arXiv:hep-ph/9810308 [hep-ph]].

[63] K. S. Babu and S. Nandi, Phys. Rev. D **62** (2000), 033002 doi:10.1103/PhysRevD.62.033002 [arXiv:hep-ph/9907213 [hep-ph]].

[64] S. F. King and G. G. Ross, Phys. Lett. B **520** (2001), 243-253 doi:10.1016/S0370-2693(01)01139-X [arXiv:hep-ph/0108112 [hep-ph]].

[65] E. Ma, Phys.Rev.Lett. 86 (2001) 2502-2504, https://doi.org/10.48550/arXiv.hep-ph/0011121

[66] R. Adhikari and A. Raychaudhuri, Phys.Rev.D 84 (2011) 033002; doi: 10.1103/PhysRevD.84.033002, ArXiv: 1004.5111 [hep-ph]

[67] M. Bordone, C. Cornella, J. Fuentes-Martin and G. Isidori, Phys. Lett. B **779**, 317-323 (2018) doi:10.1016/j.physletb.2018.02.011 [arXiv:1712.01368 [hep-ph]].

[68] A. Greljo and B. A. Stefanek, Phys. Lett. B **782**, 131-138 (2018) doi:10.1016/j.physletb.2018.05.033 [arXiv:1802.04274 [hep-ph]].

[69] B. C. Allanach and J. Davighi, JHEP **12**, 075 (2018) doi:10.1007/JHEP12(2018)075 [arXiv:1809.01158 [hep-ph]].

[70] A. Greljo, T. Opferkuch and B. A. Stefanek, Phys. Rev. Lett. **124**, no.17, 171802 (2020) doi:10.1103/PhysRevLett.124.171802 [arXiv:1910.02014 [hep-ph]].

[71] J. Fuentes-Martín and P. Stangl, Phys. Lett. B **811**, 135953 (2020) doi:10.1016/j.physletb.2020.135953 [arXiv:2004.11376 [hep-ph]].

[72] L. Allwicher, G. Isidori and A. E. Thomsen, JHEP **01**, 191 (2021) doi:10.1007/JHEP01(2021)191 [arXiv:2011.01946 [hep-ph]].

[73] J. Fuentes-Martin, G. Isidori, J. Pagès and B. A. Stefanek, Phys. Lett. B **820**, 136484 (2021) doi:10.1016/j.physletb.2021.136484 [arXiv:2012.10492 [hep-ph]].

[74] J. Davighi and J. Tooby-Smith, JHEP **09**, 193 (2022) doi:10.1007/JHEP09(2022)193 [arXiv:2201.07245 [hep-ph]].

[75] J. Davighi, G. Isidori and M. Pesut, JHEP **04**, 030 (2023) doi:10.1007/JHEP04(2023)030 [arXiv:2212.06163 [hep-ph]].

[76] J. Davighi and G. Isidori, JHEP **07**, 147 (2023) doi:10.1007/JHEP07(2023)147 [arXiv:2303.01520 [hep-ph]].

[77] J. Davighi and B. A. Stefanek, JHEP **11**, 100 (2023) doi:10.1007/JHEP11(2023)100 [arXiv:2305.16280 [hep-ph]].

[78] M. Fernández Navarro and S. F. King, JHEP **08**, 020 (2023) doi:10.1007/JHEP08(2023)020 [arXiv:2305.07690 [hep-ph]].

[79] M. Fernández Navarro, S. F. King and A. Vicente, JHEP **05**, 130 (2024) doi:10.1007/JHEP05(2024)130 [arXiv:2311.05683 [hep-ph]].

[80] J. Davighi, A. Gosnay, D. J. Miller and S. Renner, JHEP **05**, 085 (2024) doi:10.1007/JHEP05(2024)085 [arXiv:2312.13346 [hep-ph]].

[81] R. Barbieri and G. Isidori, JHEP **05**, 033 (2024) doi:10.1007/JHEP05(2024)033 [arXiv:2312.14004 [hep-ph]].

[82] B. Capdevila, A. Crivellin, J. M. Lizana and S. Pokorski, JHEP **08**, 031 (2024) doi:10.1007/JHEP08(2024)031 [arXiv:2401.00848 [hep-ph]].

[83] J. Fuentes-Martín and J. M. Lizana, JHEP **07**, 117 (2024) doi:10.1007/JHEP07(2024)117 [arXiv:2402.09507 [hep-ph]].

[84] M. Fernández Navarro, S. F. King and A. Vicente, JHEP **07**, 147 (2024) doi:10.1007/JHEP07(2024)147 [arXiv:2404.12442 [hep-ph]].

[85] A. Greljo and G. Isidori, Phys. Lett. B **856**, 138900 (2024) doi:10.1016/j.physletb.2024.138900 [arXiv:2406.01696 [hep-ph]].

[86] F. Wilczek and A. Zee, Phys. Lett. B **70** (1977), 418 [erratum: Phys. Lett. B **72** (1978), 504] doi:10.1016/0370-2693(77)90403-8

[87] G. C. Branco, Phys. Lett. B **76** (1978), 70-72 doi:10.1016/0370-2693(78)90103-X

[88] S. Pakvasa and H. Sugawara, Phys. Lett. B **73** (1978), 61-64 doi:10.1016/0370-2693(78)90172-7

[89] D. Wyler, Phys. Rev. D **19** (1979), 3369 doi:10.1103/PhysRevD.19.3369

[90] K. S. Babu and R. N. Mohapatra, Phys. Rev. Lett. **64** (1990), 2747 doi:10.1103/PhysRevLett.64.2747

[91] G. Altarelli and F. Feruglio, Rev. Mod. Phys. **82** (2010), 2701-2729 doi:10.1103/RevModPhys.82.2701 [arXiv:1002.0211 [hep-ph]].

[92] S. F. King and C. Luhn, Rept. Prog. Phys. **76** (2013), 056201 doi:10.1088/0034-4885/76/5/056201 [arXiv:1301.1340 [hep-ph]].

[93] S. T. Petcov, Eur. Phys. J. C **78** (2018) no.9, 709 doi:10.1140/epjc/s10052-018-6158-5 [arXiv:1711.10806 [hep-ph]].

[94] Neutrinos in High Energy and Astroparticle Physics, Jose Wagner Furtado Valle, Jorge Romao, ISBN: 978-3-527-67101-4 February 2015, Wiley-VCH

[95] I. Dorsner and S. M. Barr, Phys. Rev. D **65** (2002), 095004 doi:10.1103/PhysRevD.65.095004 [arXiv:hep-ph/0201207 [hep-ph]].

[96] G. F. Giudice and O. Lebedev, Phys. Lett. B **665** (2008), 79-85 doi:10.1016/j.physletb.2008.05.062 [arXiv:0804.1753 [hep-ph]].

[97] K. Tsumura and L. Velasco-Sevilla, Phys. Rev. D **81** (2010), 036012 doi:10.1103/PhysRevD.81.036012 [arXiv:0911.2149 [hep-ph]].

[98] E. L. Berger, S. B. Giddings, H. Wang and H. Zhang, Phys. Rev. D **90** (2014) no.7, 076004 doi:10.1103/PhysRevD.90.076004 [arXiv:1406.6054 [hep-ph]].

[99] J. L. Diaz-Cruz and U. J. Saldaña-Salazar, Nucl. Phys. B **913** (2016), 942-963 doi:10.1016/j.nuclphysb.2016.10.018 [arXiv:1405.0990 [hep-ph]].

[100] K. Huitu, V. Keus, N. Koivunen and O. Lebedev, JHEP **05** (2016), 026 doi:10.1007/JHEP05(2016)026 [arXiv:1603.06614 [hep-ph]].

[101] M. A. Arroyo-Ureña, A. Chakraborty, J. L. Díaz-Cruz, D. K. Ghosh, N. Khan and S. Moretti, [arXiv:2205.12641 [hep-ph]].

[102] M. Bauer, M. Carena and K. Gemmler, Phys. Rev. D **94** (2016) no.11, 115030 doi:10.1103/PhysRevD.94.115030 [arXiv:1512.03458 [hep-ph]].

[103] M. Bauer, T. Schell and T. Plehn, Phys. Rev. D **94** (2016) no.5, 056003 doi:10.1103/PhysRevD.94.056003 [arXiv:1603.06950 [hep-ph]].

[104] F. Feruglio, doi:10.1142/9789813238053_0012 [arXiv:1706.08749 [hep-ph]].

[105] T. Kobayashi and M. Tanimoto, [arXiv:2307.03384 [hep-ph]].

[106] J. C. Pati and A. Salam, Phys. Rev. D **10** (1974), 275-289 [erratum: Phys. Rev. D **11** (1975), 703-703] doi:10.1103/PhysRevD.10.275

[107] H. Georgi and S. L. Glashow, Phys. Rev. Lett. **32** (1974), 438-441 doi:10.1103/PhysRevLett.32.438

[108] S. M. Barr, Phys. Rev. D **21** (1980), 1424 doi:10.1103/PhysRevD.21.1424

[109] S. M. Barr, Phys. Rev. D **24** (1981), 1895 doi:10.1103/PhysRevD.24.1895

[110] S. Dimopoulos, Phys. Lett. B **129** (1983), 417-428 doi:10.1016/0370-2693(83)90132-6

[111] C. T. Hill, Phys. Rev. D **24** (1981), 691 doi:10.1103/PhysRevD.24.691

[112] B. Ananthanarayan, G. Lazarides and Q. Shafi, Phys. Rev. D **44** (1991), 1613-1615 doi:10.1103/PhysRevD.44.1613

[113] R. Hempfling, Phys. Rev. D **49** (1994), 6168-6172 doi:10.1103/PhysRevD.49.6168

[114] L. J. Hall, R. Rattazzi and U. Sarid, Phys. Rev. D **50** (1994), 7048-7065 doi:10.1103/PhysRevD.50.7048 [arXiv:hep-ph/9306309 [hep-ph]].

[115] G. Anderson, S. Raby, S. Dimopoulos, L. J. Hall and G. D. Starkman, Phys. Rev. D **49** (1994), 3660-3690 doi:10.1103/PhysRevD.49.3660 [arXiv:hep-ph/9308333 [hep-ph]].

[116] H. Murayama, M. Olechowski and S. Pokorski, Phys. Lett. B **371** (1996), 57-64 doi:10.1016/0370-2693(95)01611-2 [arXiv:hep-ph/9510327 [hep-ph]].

[117] R. Rattazzi and U. Sarid, Phys. Rev. D **53** (1996), 1553-1585 doi:10.1103/PhysRevD.53.1553 [arXiv:hep-ph/9505428 [hep-ph]].

[118] N. Arkani-Hamed, H. C. Cheng and L. J. Hall, Phys. Rev. D **53** (1996), 413-436 doi:10.1103/PhysRevD.53.413 [arXiv:hep-ph/9508288 [hep-ph]].

[119] H. Baer and J. Ferrandis, Phys. Rev. Lett. **87** (2001), 211803 doi:10.1103/PhysRevLett.87.211803 [arXiv:hep-ph/0106352 [hep-ph]].

[120] T. Blazek, R. Dermisek and S. Raby, Phys. Rev. D **65** (2002), 115004 doi:10.1103/PhysRevD.65.115004 [arXiv:hep-ph/0201081 [hep-ph]].

[121] G. G. Ross and L. Velasco-Sevilla, Nucl. Phys. B **653** (2003), 3-26 doi:10.1016/S0550-3213(03)00041-5 [arXiv:hep-ph/0208218 [hep-ph]].

[122] A. S. Joshipura and K. M. Patel, Phys. Rev. D **86** (2012), 035019 doi:10.1103/PhysRevD.86.035019 [arXiv:1206.3910 [hep-ph]].

[123] S. F. King, JHEP **01** (2014), 119 doi:10.1007/JHEP01(2014)119 [arXiv:1311.3295 [hep-ph]].

[124] N. Arkani-Hamed, S. Dimopoulos and G. R. Dvali, Phys. Lett. B **429** (1998), 263-272 doi:10.1016/S0370-2693(98)00466-3 [arXiv:hep-ph/9803315 [hep-ph]].

[125] L. Randall and R. Sundrum, Phys. Rev. Lett. **83** (1999), 3370-3373 doi:10.1103/PhysRevLett.83.3370 [arXiv:hep-ph/9905221 [hep-ph]].

[126] T. Gherghetta and A. Pomarol, Nucl. Phys. B **586** (2000), 141-162 doi:10.1016/S0550-3213(00)00392-8 [arXiv:hep-ph/0003129 [hep-ph]].

[127] M. Blanke, A. J. Buras, B. Duling, S. Gori and A. Weiler, JHEP **03** (2009), 001 doi:10.1088/1126-6708/2009/03/001 [arXiv:0809.1073 [hep-ph]].

[128] J. Fuentes-Martin, G. Isidori, J. M. Lizana, N. Selimovic and B. A. Stefanek, Phys. Lett. B **834** (2022), 137382 doi:10.1016/j.physletb.2022.137382 [arXiv:2203.01952 [hep-ph]].

[129] Y. Grossman and M. Neubert, Phys. Lett. B **474** (2000), 361-371 doi:10.1016/S0370-2693(00)00054-X [arXiv:hep-ph/9912408 [hep-ph]].

[130] S. Casagrande, F. Goertz, U. Haisch, M. Neubert and T. Pfoh, JHEP **10** (2008), 094 doi:10.1088/1126-6708/2008/10/094 [arXiv:0807.4937 [hep-ph]].

[131] M. Bauer, S. Casagrande, U. Haisch and M. Neubert, JHEP **09** (2010), 017 doi:10.1007/JHEP09(2010)017 [arXiv:0912.1625 [hep-ph]].

[132] S. Weinberg, Phys. Rev. D **13** (1976), 974-996 doi:10.1103/PhysRevD.19.1277

[133] L. Susskind, Phys. Rev. D **20** (1979), 2619-2625 doi:10.1103/PhysRevD.20.2619

[134] J. C. Pati, A. Salam and J. A. Strathdee, Phys. Lett. B **59** (1975), 265-268 doi:10.1016/0370-2693(75)90042-8

[135] D. B. Kaplan, Nucl. Phys. B **365** (1991), 259-278 doi:10.1016/S0550-3213(05)80021-5

[136] R. Barbieri, D. Buttazzo, F. Sala and D. M. Straub, JHEP **07** (2012), 181 doi:10.1007/JHEP07(2012)181 [arXiv:1203.4218 [hep-ph]].

[137] A. Rasin, Phys. Rev. D **58**, 096012 (1998) doi:10.1103/PhysRevD.58.096012 [arXiv:hep-ph/9802356 [hep-ph]].

[138] G. G. Ross in “flavor Physics for the Millennium", Editor Jonathan L. Rosner, World Scientific, Singapore, 2001

[139] P. Minkowski, Phys. Lett. B **67** (1977), 421-428 doi:10.1016/0370-2693(77)90435-X, M. Gell-Mann, P. Ramond, and R. Slansky, *Supergravity* (P. van Nieuwenhuizen et al. eds.), North Holland, Amsterdam, 1980, p. 315; T. Yanagida, in *Proceedings of the Workshop on the Unified Theory and the*

Baryon Number in the Universe (O. Sawada and A. Sugamoto, eds.), KEK, Tsukuba, Japan, 1979, p. 95; S. L. Glashow, *The future of elementary particle physics*, in *Proceedings of the 1979 Cargèse Summer Institute on Quarks and Leptons* (M. Lévy et al. eds.), Plenum Press, New York, 1980, pp. 687–713; R. N. Mohapatra and G. Senjanović, Phys. Rev. Lett. **44**, 912 (1980); P. Ramond, hep-ph/9809459.

[140] G. Abbas, M. Z. Abyaneh and R. Srivastava, Phys. Rev. D **95**, no.7, 075005 (2017) doi:10.1103/PhysRevD.95.075005 [arXiv:1609.03886 [hep-ph]].

[141] G. Abbas, M. Z. Abyaneh, A. Biswas, S. Gupta, M. Patra, G. Rajasekaran and R. Srivastava, Int. J. Mod. Phys. A **31**, no.17, 1650095 (2016) doi:10.1142/S0217751X16500950 [arXiv:1506.02603 [hep-ph]].

[142] G. Abbas, S. Gupta, G. Rajasekaran and R. Srivastava, Phys. Rev. D **89**, no.9, 093009 (2014) doi:10.1103/PhysRevD.89.093009 [arXiv:1401.3399 [hep-ph]].

[143] G. Abbas, S. Gupta, G. Rajasekaran and R. Srivastava, Phys. Rev. D **91**, no.11, 111301 (2015) doi:10.1103/PhysRevD.91.111301 [arXiv:1312.7384 [hep-ph]].

[144] L. Calibbi, A. Crivellin and B. Zaldívar, Phys. Rev. D **92**, no.1, 016004 (2015) doi:10.1103/PhysRevD.92.016004 [arXiv:1501.07268 [hep-ph]].

[145] M. Fedele, A. Mastroddi and M. Valli, JHEP **03**, 135 (2021) doi:10.1007/JHEP03(2021)135 [arXiv:2009.05587 [hep-ph]].

[146] P. Huber, K. Scholberg, E. Worcester, J. Asaadi, A. B. Balantekin, N. Bowden, P. Coloma, P. B. Denton, A. de Gouvêa and L. Fields, *et al.* [arXiv:2211.08641 [hep-ex]].

[147] A. J. Buras, F. De Fazio, J. Girrbach, R. Knegjens and M. Nagai, JHEP **1306**, 111 (2013).

[148] A. Crivellin, A. Kokulu and C. Greub, Phys. Rev. D **87**, no. 9, 094031 (2013).

[149] M. Ciuchini *et al.*, JHEP **9810** (1998) 008 doi:10.1088/1126-6708/1998/10/008 [hep-ph/9808328].

[150] D. Becirevic, V. Gimenez, G. Martinelli, M. Papinutto and J. Reyes, JHEP **04** (2002), 025 doi:10.1088/1126-6708/2002/04/025 [arXiv:hep-lat/0110091 [hep-lat]].

[151] M. Bona *et al.* [UTfit Collaboration], JHEP **0803**, 049 (2008), http://www.utfit.org/UTfit/

[152] P.A. Zyla et al. (Particle Data Group), Prog. Theor. Exp. Phys. 2020, 083C01 (2020) and 2021 update

[153] Y. Aoki *et al.*, [arXiv:2111.09849v1 [hep-lat]].

[154] J. Brod and M. Gorbahn, Next-to-next-to-leading-order charm-quark contribution to the CP violation parameter ε_K and ΔM_K, Phys.Rev.Lett. 108 (2012) 121801, [1108.2036]

[155] Buchalla, Gerhard and Buras, Andrzej J. and Lautenbacher, Markus E., doi:10.1103/RevModPhys.68.1125, https://link.aps.org/doi/10.1103/RevModPhys.68.1125

[156] J. Brod and M. Gorbahn, ε_K at next-to-next-to-leading order: the charm-top-quark contribution, Phys. Rev. D82 (2010) 094026, [1007.0684].

[157] Y. Amhis *et al.* [HFLAV], Eur. Phys. J. C **77**, no.12, 895 (2017) doi:10.1140/epjc/s10052-017-5058-4 [arXiv:1612.07233 [hep-ex]].

[158] D. Becirevic, M. Ciuchini, E. Franco, V. Gimenez, G. Martinelli, A. Masiero, M. Papinutto, J. Reyes and L. Silvestrini, Nucl. Phys. B **634** (2002), 105-119 doi:10.1016/S0550-3213(02)00291-2 [arXiv:hep-ph/0112303 [hep-ph]].

[159] A. Donini, V. Gimenez, L. Giusti and G. Martinelli, Phys. Lett. B **470**, 233-242 (1999) doi:10.1016/S0370-2693(99)01300-3 [arXiv:hep-lat/9910017 [hep-lat]].

[160] J. Charles, S. Descotes-Genon, Z. Ligeti, S. Monteil, M. Papucci, K. Trabelsi and L. Vale Silva, Phys. Rev. D **102**, no.5, 056023 (2020) doi:10.1103/PhysRevD.102.056023 [arXiv:2006.04824 [hep-ph]].

[161] M. Bona [UTfit], PoS **CKM2016**, 143 (2017) doi:10.22323/1.291.0143

[162] T. Inami and C. S. Lim, Prog. Theor. Phys. **65**, 297 (1981) [erratum: Prog. Theor. Phys. **65**, 1772 (1981)] doi:10.1143/PTP.65.297

[163] A. J. Buras, J. Girrbach, D. Guadagnoli and G. Isidori, Eur. Phys. J. C **72**, 2172 (2012) doi:10.1140/epjc/s10052-012-2172-1 [arXiv:1208.0934 [hep-ph]].

[164] Y. Amhis *et al.* [HFLAV], [arXiv:2206.07501 [hep-ex]].

[165] R. Aaij *et al.* [LHCb], Phys. Rev. Lett. **128**, no.4, 041801 (2022) doi:10.1103/PhysRevLett.128.041801 [arXiv:2108.09284 [hep-ex]].

[166] R. Aaij *et al.* [LHCb], Phys. Rev. D **105**, no.1, 012010 (2022) doi:10.1103/PhysRevD.105.012010 [arXiv:2108.09283 [hep-ex]].

[167] K. De Bruyn, R. Fleischer, R. Knegjens, P. Koppenburg, M. Merk, A. Pellegrino and N. Tuning, Phys. Rev. Lett. **109**, 041801 (2012) doi:10.1103/PhysRevLett.109.041801 [arXiv:1204.1737 [hep-ph]].

[168] R. Fleischer, [arXiv:1212.4967 [hep-ph]].

[169] [CMS], CMS-PAS-BPH-21-006.

[170] W. Altmannshofer and F. Archilli, [arXiv:2206.11331 [hep-ph]].

[171] K. De Bruyn, R. Fleischer, R. Knegjens, P. Koppenburg, M. Merk and N. Tuning, Phys. Rev. D **86** (2012), 014027 doi:10.1103/PhysRevD.86.014027 [arXiv:1204.1735 [hep-ph]].

[172] M. Gorbahn and U. Haisch, Phys. Rev. Lett. **97**, 122002 (2006) doi:10.1103/PhysRevLett.97.122002 [arXiv:hep-ph/0605203 [hep-ph]].

[173] R. Aaij *et al.* [LHCb], Phys. Lett. B **725**, 15-24 (2013) doi:10.1016/j.physletb.2013.06.037 [arXiv:1305.5059 [hep-ex]].

[174] A. M. Baldini *et al.* [MEG], Eur. Phys. J. C **76**, no.8, 434 (2016) doi:10.1140/epjc/s10052-016-4271-x [arXiv:1605.05081 [hep-ex]].

[175] A. M. Baldini *et al.* [MEG II], Eur. Phys. J. C **78**, no.5, 380 (2018) doi:10.1140/epjc/s10052-018-5845-6 [arXiv:1801.04688 [physics.ins-det]].

[176] B. Aubert *et al.* [BaBar], Phys. Rev. Lett. **104**, 021802 (2010) doi:10.1103/PhysRevLett.104.021802 [arXiv:0908.2381 [hep-ex]].

[177] E. Kou *et al.* [Belle-II], PTEP **2019**, no.12, 123C01 (2019) [erratum: PTEP **2020**, no.2, 029201 (2020)] doi:10.1093/ptep/ptz106 [arXiv:1808.10567 [hep-ex]].

[178] W. H. Bertl *et al.* [SINDRUM II], Eur. Phys. J. C **47**, 337-346 (2006) doi:10.1140/epjc/s2006-02582-x

[179] M. L. Wong [COMET], PoS **FPCP2015**, 059 (2015) doi:10.22323/1.248.0059

[180] Akiro SATO https://indico.fnal.gov/event/46669/contributions/203149/attachments/138299/173056/201210_PRISM_sato.pdf

[181] R. M. Carey *et al.* [Mu2e], doi:10.2172/952028

[182] N. Teshima [DeeMe], SciPost Phys. Proc. **1**, 051 (2019) doi:10.21468/SciPostPhysProc.1.051 [arXiv:1811.04235 [physics.ins-det]].

[183] S. Davidson and B. Echenard, Eur. Phys. J. C **82**, no.9, 836 (2022) doi:10.1140/epjc/s10052-022-10773-4 [arXiv:2204.00564 [hep-ph]].

[184] Y. Kuno, Nucl. Phys. B Proc. Suppl. **225-227**, 228-231 (2012) doi:10.1016/j.nuclphysbps.2012.02.047

[185] U. Bellgardt *et al.* [SINDRUM], Nucl. Phys. B **299**, 1-6 (1988) doi:10.1016/0550-3213(88)90462-2

[186] A. Blondel, A. Bravar, M. Pohl, S. Bachmann, N. Berger, M. Kiehn, A. Schoning, D. Wiedner, B. Windelband and P. Eckert, *et al.* [arXiv:1301.6113 [physics.ins-det]].

[187] K. Hayasaka, K. Inami, Y. Miyazaki, K. Arinstein, V. Aulchenko, T. Aushev, A. M. Bakich, A. Bay, K. Belous and V. Bhardwaj, *et al.* Phys. Lett. B **687**, 139-143 (2010) doi:10.1016/j.physletb.2010.03.037 [arXiv:1001.3221 [hep-ex]].

[188] M. A. Shifman, A. I. Vainshtein and V. I. Zakharov, Phys. Lett. B **78**, 443-446 (1978) doi:10.1016/0370-2693(78)90481-1

[189] A. Crivellin, M. Hoferichter and M. Procura, Phys. Rev. D **89**, 054021 (2014) doi:10.1103/PhysRevD.89.054021 [arXiv:1312.4951 [hep-ph]].

[190] A. Crivellin, M. Hoferichter and M. Procura, Phys. Rev. D **89**, 093024 (2014) doi:10.1103/PhysRevD.89.093024 [arXiv:1404.7134 [hep-ph]].

[191] P. Junnarkar and A. Walker-Loud, Phys. Rev. D **87**, 114510 (2013) doi:10.1103/PhysRevD.87.114510 [arXiv:1301.1114 [hep-lat]].

[192] R. Kitano, M. Koike and Y. Okada, Phys. Rev. D **66**, 096002 (2002) [erratum: Phys. Rev. D **76**, 059902 (2007)] doi:10.1103/PhysRevD.76.059902 [arXiv:hep-ph/0203110 [hep-ph]].

[193] T. Goto, R. Kitano and S. Mori, Phys. Rev. D **92**, 075021 (2015) doi:10.1103/PhysRevD.92.075021 [arXiv:1507.03234 [hep-ph]].

[194] A. M. Sirunyan *et al.* [CMS], JHEP **06** (2018), 127 [erratum: JHEP **03** (2019), 128] doi:10.1007/JHEP06(2018)127 [arXiv:1804.01939 [hep-ex]].

[195] G. Aad *et al.* [ATLAS], JHEP **07**, 200 (2023) doi:10.1007/JHEP07(2023)200 [arXiv:2211.02617 [hep-ex]].

[196] A. M. Sirunyan *et al.* [CMS], JHEP **03**, 034 (2020) doi:10.1007/JHEP03(2020)034 [arXiv:1912.01594 [hep-ex]].

[197] G. Aad *et al.* [ATLAS], Phys. Lett. B **822**, 136651 (2021) doi:10.1016/j.physletb.2021.136651 [arXiv:2102.13405 [hep-ex]].

[198] A. M. Sirunyan *et al.* [CMS], Phys. Rev. D **98** (2018) no.9, 092001 doi:10.1103/PhysRevD.98.092001 [arXiv:1809.00327 [hep-ex]].

[199] J. A. Aguilar-Saavedra and G. C. Branco, Phys. Lett. B **495**, 347 (2000).

[200] A. D. Martin, W. J. Stirling, R. S. Thorne and G. Watt, Eur. Phys. J. C **63**, 189-285 (2009) doi:10.1140/epjc/s10052-009-1072-5 [arXiv:0901.0002 [hep-ph]].

[201] A. Alloul, N. D. Christensen, C. Degrande, C. Duhr and B. Fuks, Comput. Phys. Commun. **185**, 2250-2300 (2014) doi:10.1016/j.cpc.2014.04.012 [arXiv:1310.1921 [hep-ph]].

[202] J. Alwall, R. Frederix, S. Frixione, V. Hirschi, F. Maltoni, O. Mattelaer, H. S. Shao, T. Stelzer, P. Torrielli and M. Zaro, JHEP **07**, 079 (2014) doi:10.1007/JHEP07(2014)079 [arXiv:1405.0301 [hep-ph]].

[203] G. Aad *et al.* [ATLAS], JHEP **03**, 145 (2020) doi:10.1007/JHEP03(2020)145 [arXiv:1910.08447 [hep-ex]].

[204] A. M. Sirunyan *et al.* [CMS], JHEP **05**, 033 (2020) doi:10.1007/JHEP05(2020)033 [arXiv:1911.03947 [hep-ex]].

[205] M. Aaboud *et al.* [ATLAS], JHEP **01**, 055 (2018) doi:10.1007/JHEP01(2018)055 [arXiv:1709.07242 [hep-ex]].

[206] A. M. Sirunyan *et al.* [CMS], JHEP **09** (2018), 007 doi:10.1007/JHEP09(2018)007 [arXiv:1803.06553 [hep-ex]].

[207] G. Aad *et al.* [ATLAS], Phys. Lett. B **796** (2019), 68-87 doi:10.1016/j.physletb.2019.07.016 [arXiv:1903.06248 [hep-ex]].

[208] A. M. Sirunyan *et al.* [CMS], JHEP **07** (2021), 208 doi:10.1007/JHEP07(2021)208 [arXiv:2103.02708 [hep-ex]].

[209] G. Aad *et al.* [ATLAS], JHEP **23** (2020), 082 doi:10.1007/JHEP10(2023)082 [arXiv:2307.08567 [hep-ex]].

[210] A. Tumasyan *et al.* [CMS], JHEP **05** (2023), 227 doi:10.1007/JHEP05(2023)227 [arXiv:2205.06709 [hep-ex]].

[211] A. Tumasyan *et al.* [CMS], Phys. Rev. D **108** (2023) no.1, 012009 doi:10.1103/PhysRevD.108.012009 [arXiv:2205.01835 [hep-ex]].

[212] M. Aaboud *et al.* [ATLAS], Phys. Rev. D **99** (2019) no.9, 092004 doi:10.1103/PhysRevD.99.092004 [arXiv:1902.10077 [hep-ex]].

[213] G. Aad *et al.* [ATLAS], JHEP **10** (2020), 061 doi:10.1007/JHEP10(2020)061 [arXiv:2005.05138 [hep-ex]].

[214] A. M. Sirunyan *et al.* [CMS], JHEP **04** (2019), 031 doi:10.1007/JHEP04(2019)031 [arXiv:1810.05905 [hep-ex]].

[215] https://indico.cern.ch/event/284800/contributions/1635340/attachments/527023/726700/collider-reach.pdf

[216] A. Tumasyan *et al.* [CMS], JHEP **07**, 073 (2023) doi:10.1007/JHEP07(2023)073 [arXiv:2208.02717 [hep-ex]].

[217] G. Aad *et al.* [ATLAS], JHEP **07**, 155 (2023) doi:10.1007/JHEP07(2023)155 [arXiv:2211.04172 [hep-ex]].

[218] ATLAS-CONF-2023-035, 15 Jun 2023.

[219] [CMS], CMS-PAS-HIG-20-002.

[220] G. Aad *et al.* [ATLAS], JHEP **07**, 203 (2023) doi:10.1007/JHEP07(2023)203 [arXiv:2211.01136 [hep-ex]].

[221] A. M. Sirunyan *et al.* [CMS], Eur. Phys. J. C **80** (2020) no.2, 75 doi:10.1140/epjc/s10052-019-7593-7 [arXiv:1908.06463 [hep-ex]].

[222] M. Aaboud *et al.* [ATLAS], Phys. Rev. Lett. **121**, no.19, 191801 (2018) [erratum: Phys. Rev. Lett. **122**, no.8, 089901 (2019)] doi:10.1103/PhysRevLett.121.191801 [arXiv:1808.00336 [hep-ex]].

[223] A. M. Sirunyan *et al.* [CMS], Phys. Rev. D **96**, no.7, 072004 (2017) doi:10.1103/PhysRevD.96.072004 [arXiv:1707.00350 [hep-ex]].

[224] M. Aaboud *et al.* [ATLAS], JHEP **01**, 030 (2019) doi:10.1007/JHEP01(2019)030 [arXiv:1804.06174 [hep-ex]].

[225] A. M. Sirunyan *et al.* [CMS], JHEP **08**, 152 (2018) doi:10.1007/JHEP08(2018)152 [arXiv:1806.03548 [hep-ex]].

[226] G. Aad *et al.* [ATLAS], Phys. Rev. D **105**, no.1, 012006 (2022) doi:10.1103/PhysRevD.105.012006 [arXiv:2110.00313 [hep-ex]].

[227] A. Hayrapetyan *et al.* [CMS], [arXiv:2402.13358 [hep-ex]].

[228] M. Aaboud *et al.* [ATLAS], JHEP **10**, 031 (2018) doi:10.1007/JHEP10(2018)031 [arXiv:1806.07355 [hep-ex]].

[229] A. Hayrapetyan *et al.* [CMS], [arXiv:2403.10341 [hep-ex]].

[230] G. Abbas, R. Adhikari, E. J. Chun and N. Singh, Eur. Phys. J. Plus **140** (2025) no.1, 73 doi:10.1140/epjp/s13360-025-06008-6 [arXiv:2308.14811 [hep-ph]].

[231] F. Björkeroth, E. J. Chun and S. F. King, JHEP **08**, 117 (2018) doi:10.1007/JHEP08(2018)117 [arXiv:1806.00660 [hep-ph]].

[232] AxionLimits, https://cajohare.github.io/AxionLimits/

[233] CMS collaboration, "Search for a standard model-like Higgs boson in the mass range between 70 and 110 GeV in the diphoton final state in proton-proton collisions at $\sqrt{s} = 13$ TeV," CMS-PAS-HIG-20-002, 2023.

[234] C. Arcangeletti. on behalf of ATLAS collaboration, LHC Seminar https://indico.cern.ch/event/1281604/attachments/2660420/4608571/LHCSeminarArcangeletti_final.pdf, 7^th of June, 2023.

[235] T. Biekötter, S. Heinemeyer and G. Weiglein, “95.4 GeV diphoton excess at ATLAS and CMS,” Phys. Rev. D **109** (2024), 3.

[236] R. Barate *et al.* [LEP Working Group for Higgs boson searches, ALEPH, DELPHI, L3 and OPAL], “Search for the standard model Higgs boson at LEP,” Phys. Lett. B **565** (2003), 61-75.

[237] J. Cao, X. Guo, Y. He, P. Wu and Y. Zhang, “Diphoton signal of the light Higgs boson in natural NMSSM,” Phys. Rev. D **95** (2017), 116001.

[238] T. Biekötter, M. Chakraborti and S. Heinemeyer, “A 96 GeV Higgs boson in the N2HDM,” Eur. Phys. J. C **80** (2020), 2.

[239] S. Heinemeyer, C. Li, F. Lika, G. Moortgat-Pick and S. Paasch, “Phenomenology of a 96 GeV Higgs boson in the 2HDM with an additional singlet,” Phys. Rev. D **106** (2022), 075003.

[240] T. Biekötter, S. Heinemeyer and G. Weiglein, “Mounting evidence for a 95 GeV Higgs boson,” JHEP **08** (2022), 201.

[241] J. A. Aguilar-Saavedra, H. B. Câmara, F. R. Joaquim and J. F. Seabra, “Confronting the 95 GeV excesses within the U(1)’-extended next-to-minimal 2HDM,” Phys. Rev. D **108** (2023), 075020.

[242] K. Choi, S. H. Im, K. S. Jeong and C. B. Park, “Light Higgs bosons in the general NMSSM,” Eur. Phys. J. C **79** (2019), 956.

[243] S. Ma, K. Wang and J. Zhu, "Higgs decay to light (pseudo)scalars in the semi-constrained NMSSM," Chin. Phys. C **45** (2021), 023113.

[244] W. Li, H. Qiao and J. Zhu, "Light Higgs boson in the NMSSM confronted with the CMS di-photon and di-tau excesses," Chin. Phys. C **47** (2023), 123102.

[245] U. Ellwanger and C. Hugonie, "Additional Higgs Bosons near 95 and 650 GeV in the NMSSM," Eur. Phys. J. C **83** (2023), 1138.

[246] P. S. B. Dev, R. N. Mohapatra and Y. Zhang, "Explanation of the 95 GeV $\gamma\gamma$ and $b\bar{b}$ excesses in the minimal left-right symmetric model," Phys. Lett. B **849** (2024), 138481.

[247] C. Bonilla, A. E. Carcamo Hernandez, S. Kovalenko, H. Lee, R. Pasechnik and I. Schmidt, "Fermion mass hierarchy in an extended left-right symmetric model," JHEP **12** (2023), 075.

[248] C. X. Liu, Y. Zhou, X. Y. Zheng, J. Ma, T. F. Feng and H. B. Zhang, "95 GeV excess in a CP-violating μ-from-ν SSM," Phys. Rev. D **109** (2024), 056001.

[249] W. Li, H. Qiao, K. Wang and J. Zhu, "Light dark matter confronted with the 95 GeV diphoton excess," arXiv:2312.17599.

[250] A. Ahriche, M. L. Bellilet, M. O. Khojali, M. Kumar and A. T. Mulaudzi, "The scale invariant scotogenic model: CDF-II W-boson mass and the 95 GeV excesses," arXiv:2311.08297.

[251] J. Cao, X. Jia, J. Lian and L. Meng, "95 GeV diphoton and $b\bar{b}$ excesses in the general next-to-minimal supersymmetric standard model," Phys. Rev. D **109** (2024), 075001.

[252] M. Maniatis and O. Nachtmann, “CMS results for the $\gamma\gamma$ production at the LHC: do they give a hint for a Higgs boson of the maximally CP symmetric two-Higgs-doublet model?,” arXiv:2309.04869.

[253] A. Belyaev, R. Benbrik, M. Boukidi, M. Chakraborti, S. Moretti and S. Semlali, “Explanation of the hints for a 95 GeV Higgs boson within a 2-Higgs Doublet Model,” JHEP **05** (2024), 209.

[254] D. Azevedo, T. Biekötter and P. M. Ferreira, “2HDM interpretations of the CMS diphoton excess at 95 GeV,” JHEP **11** (2023), 017.

[255] D. Bhatia, N. Desai and S. Dwivedi, “Discovery prospects of a light charged Higgs near the fermiophobic region of Type-I 2HDM,” JHEP **06** (2023), 100.

[256] T. K. Chen, C. W. Chiang, S. Heinemeyer and G. Weiglein, “95 GeV Higgs boson in the Georgi-Machacek model,” Phys. Rev. D **109** (2024), 075043.

[257] A. Ahriche, “The 95 GeV Excess in the Georgi-Machacek Model: Single or Twin Peak Resonance,” arXiv:2312.10484.

[258] G. Arcadi, G. Busoni, D. Cabo-Almeida and N. Krishnan, “Is there a (Pseudo)Scalar at 95 GeV?,” arXiv:2311.14486.

[259] D. Borah, S. Mahapatra, P. K. Paul and N. Sahu, “Scotogenic U(1)Lμ-Lτ origin of (g-2)μ, W-mass anomaly and 95 GeV excess,” Phys. Rev. D **109** (2024), 055021.

[260] S. Banik, G. Coloretti, A. Crivellin and B. Mellado, “Uncovering New Higgses in the LHC Analyses of Differential $t\bar{t}$ Cross Sections,” arXiv:2308.07953.

[261] J. Dutta, J. Lahiri, C. Li, G. Moortgat-Pick, S. F. Tabira and J. A. Ziegler, "Dark Matter Phenomenology in 2HDMS in light of the 95 GeV excess," arXiv:2308.05653.

[262] S. Bhattacharya, G. Coloretti, A. Crivellin, S. E. Dahbi, Y. Fang, M. Kumar and B. Mellado, "Growing Excesses of New Scalars at the Electroweak Scale," arXiv:2306.17209.

[263] S. Ashanujjaman, S. Banik, G. Coloretti, A. Crivellin, B. Mellado and A. T. Mulaudzi, "SU(2)L triplet scalar as the origin of the 95 GeV excess?," Phys. Rev. D **108** (2023), L091704.

[264] P. Escribano, V. M. Lozano and A. Vicente, "Scotogenic explanation for the 95 GeV excesses," Phys. Rev. D **108** (2023), 115001.

[265] T. Biekötter, S. Heinemeyer and G. Weiglein, "The CMS di-photon excess at 95 GeV in view of the LHC Run 2 results," Phys. Lett. B **846** (2023), 138217.

[266] S. Banik, A. Crivellin, S. Iguro and T. Kitahara, "Asymmetric di-Higgs signals of the next-to-minimal 2HDM with a U(1) symmetry," Phys. Rev. D **108** (2023), 075011.

[267] G. Coloretti, A. Crivellin, S. Bhattacharya and B. Mellado, "Searching for low-mass resonances decaying into W bosons," Phys. Rev. D **108** (2023), 035026.

[268] A. Ahriche, "Constraining the Georgi-Machacek model with a light Higgs boson," Phys. Rev. D **107** (2023), 015006.

[269] R. Benbrik, M. Boukidi, S. Moretti and S. Semlali, "Explaining the 96 GeV Di-photon anomaly in a generic 2HDM Type-III," Phys. Lett. B **832** (2022), 137245.

[270] T. Biekötter, S. Heinemeyer and G. Weiglein, “Excesses in the low-mass Higgs-boson search and the W-boson mass measurement,” Eur. Phys. J. C **83** (2023), 450.

[271] T. Biekötter, A. Grohsjean, S. Heinemeyer, C. Schwanenberger and G. Weiglein, “Possible indications for new Higgs bosons in the reach of the LHC: N2HDM and NMSSM interpretations,” Eur. Phys. J. C **82** (2022), 178.

[272] A. A. Abdelalim, B. Das, S. Khalil and S. Moretti, “Di-photon decay of a light Higgs state in the BLSSM,” Nucl. Phys. B **985** (2022), 116013.

[273] T. Biekötter, M. Chakraborti and S. Heinemeyer, “The “96 GeV excess” at the LHC,” Int. J. Mod. Phys. A **36** (2021), 2142018.

[274] J. A. Aguilar-Saavedra and F. R. Joaquim, “Multiphoton signals of a (96 GeV?) stealth boson,” Eur. Phys. J. C **80** (2020), 403.

[275] J. Cao, X. Jia, Y. Yue, H. Zhou and P. Zhu, “96 GeV diphoton excess in seesaw extensions of the natural NMSSM,” Phys. Rev. D **101** (2020), 055008.

[276] A. Kundu, S. Maharana and P. Mondal, “A 96 GeV scalar tagged to dark matter models,” Nucl. Phys. B **955** (2020), 115057.

[277] J. Cao, X. Jia and J. Lian, “Unified Interpretation of Muon g-2 anomaly, 95 GeV Diphoton, and $b\bar{b}$ Excesses in the General Next-to-Minimal Supersymmetric Standard Model,” arXiv:2402.15847.

[278] J. Kalinowski and W. Kotlarski, “Interpreting 95 GeV di-photon/$b\overline{b}$ excesses as a lightest Higgs boson of the MRSSM,” JHEP **07** (2024), 037.

[279] U. Ellwanger, C. Hugonie, S. F. King and S. Moretti, “NMSSM Explanation for Excesses in the Search for Neutralinos and Charginos and a 95 GeV Higgs Boson,” arXiv:2404.19338.

[280] R. Benbrik, M. Boukidi and S. Moretti, “Superposition of CP-Even and CP-Odd Higgs Resonances: Explaining the 95 GeV Excesses within a Two-Higgs Doublet Model,” arXiv:2405.02899.

[281] J. Lian, “The 95GeV Excesses in the $\mathbb{Z}_3$-symmetric Next-to Minimal Supersymmetric Standard Model,” arXiv:2406.10969.

[282] J. L. Yang, M. H. Guo, W. H. Zhang, H. B. Zhang and T. F. Feng, “Explaining the possible 95 GeV excesses in the $B-L$ symmetric SSM,” arXiv:2406.01926.

[283] P. Janot, “The infamous 95 GeV $b\bar{b}$ excess at LEP: Two b or not two b?,” arXiv:2407.10948.

[284] K. Wang and J. Zhu, Chin. Phys. C **48**, no.7, 073105 (2024) doi:10.1088/1674-1137/ad4268 [arXiv:2402.11232 [hep-ph]].

[285] J. Gao, J. Ma, L. Wang and H. Xu, [arXiv:2408.03705 [hep-ph]].

[286] S. Yaser Ayazi, M. Hosseini, S. Paktinat Mehdiabadi and R. Rouzbehi, Phys. Rev. D **110**, no.5, 055004 (2024) doi:10.1103/PhysRevD.110.055004 [arXiv:2405.01132 [hep-ph]].

[287] A. Khanna, S. Moretti and A. Sarkar, [arXiv:2409.02587 [hep-ph]].

[288] B. Ait-Ouazghour, M. Chabab and K. Goure, [arXiv:2410.11140 [hep-ph]].

[289] S. Baek, P. Ko, Y. Omura and C. Yu, [arXiv:2412.02178 [hep-ph]].

[290] S. Banik, G. Coloretti, A. Crivellin and H. E. Haber, [arXiv:2412.00523 [hep-ph]].

[291] T. Mondal, S. Moretti and P. Sanyal, [arXiv:2412.00474 [hep-ph]].

[292] S. Gao, S. M. Zhao, L. Ruan, X. X. Dong and T. F. Feng, [arXiv:2411.13261 [hep-ph]].

[293] A. Arhrib, K. H. Phan, V. Q. Tran and T. C. Yuan, [arXiv:2405.03127 [hep-ph]].

[294] Z. z. Xing, H. Zhang and S. Zhou, Phys. Rev. D **77**, 113016 (2008) doi:10.1103/PhysRevD.77.113016 [arXiv:0712.1419 [hep-ph]].

[295] H. Harari and N. Seiberg, Phys. Lett. B **102**, 263-266 (1981) doi:10.1016/0370-2693(81)90871-6

[296] A. Chatterjee, M. Frasca, A. Ghoshal and S. Groote, [arXiv:2407.21179 [hep-ph]].

[297] K. I. Aoki and M. Bando, Prog. Theor. Phys. **70**, 272 (1983) doi:10.1143/PTP.70.272

[298] V. A. Miransky, “Dynamical symmetry breaking in quantum field theories,” ISBN: 978-981-02-1558-3 World Scientific, Singapore

Appendix A

Benchmark points for the Yukawa couplings of $\mathcal{Z}_N \times \mathcal{Z}_M$ flavour symmetry

We perform a χ^2 fit to the quark and charged-lepton masses, along with the quark mixing parameters, by defining,

$$\begin{aligned}
\chi^2 &= \frac{(m_q - m_q^{\rm model})^2}{\sigma_{m_q}^2} + \frac{(m_\ell - m_\ell^{\rm model})^2}{\sigma_{m_\ell}^2} + \frac{(\sin\theta_{ij} - \sin\theta_{ij}^{\rm model})^2}{\sigma_{\sin\theta_{ij}}^2} \\
&+ \frac{(\sin 2\beta - \sin 2\beta^{\rm model})^2}{\sigma_{\sin 2\beta}^2} + \frac{(\alpha - \alpha^{\rm model})^2}{(\sigma_\alpha)^2} + \frac{(\gamma - \gamma^{\rm model})^2}{(\sigma_\gamma)^2}, \qquad \text{(A.1)}
\end{aligned}$$

where $q = \{u, d, c, s, t, b\}$, $\ell = \{e, \mu, \tau\}$, and $i, j = 1, 2, 3$. The CKM matrix phases in the standard parametrization are given by,

$$\begin{aligned}
\beta^{\rm model} &= \arg\left(-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right), \\
\alpha^{\rm model} &= \arg\left(-\frac{V_{td}V_{tb}^*}{V_{ud}V_{ub}^*}\right), \qquad \text{(A.2)} \\
\gamma^{\rm model} &= \arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right).
\end{aligned}$$

To reproduce the fermion masses, we use the following values of the quark and charged-lepton masses at 1TeV [294],

$$\begin{aligned}
\{m_t, m_c, m_u\} &\simeq \{150.7 \pm 3.4,\ 0.532^{+0.074}_{-0.073},\ (1.10^{+0.43}_{-0.37}) \times 10^{-3}\}\ \text{GeV},\\
\{m_b, m_s, m_d\} &\simeq \{2.43 \pm 0.08,\ 4.7^{+1.4}_{-1.3} \times 10^{-2},\ 2.50^{+1.08}_{-1.03} \times 10^{-3}\}\ \text{GeV},\\
\{m_\tau, m_\mu, m_e\} &\simeq \{1.78 \pm 0.2,\ 0.105^{+9.4\times 10^{-9}}_{-9.3\times 10^{-9}},\ 4.96 \pm 0.00000043 \times 10^{-4}\}\ \text{GeV}.
\end{aligned} \tag{A.3}$$

The magnitudes and phases of the CKM mixing elements are [152],

$$\begin{aligned}
|V_{ud}| &= 0.97370 \pm 0.00014, |V_{cb}| = 0.0410 \pm 0.0014, |V_{ub}| = 0.00382 \pm 0.00024,\\
\sin 2\beta &= 0.699 \pm 0.017,\ \alpha = (84.9^{+5.1}_{-4.5})^\circ,\ \gamma = (72.1^{+4.1}_{-4.5})^\circ, \delta = 1.196^{+0.045}_{-0.043}
\end{aligned} \tag{A.4}$$

The $\mathscr{Z}_2 \times \mathscr{Z}_5$ model

The dimensionless coefficients $y_{ij}^{u,d,\ell,\nu} = |y_{ij}^{u,d,\ell,\nu}| e^{i\phi_{ij}^{q,\ell,\nu}}$ are scanned with $|y_{ij}^{u,d,\ell,\nu}| \in [0.1, 4\pi]$ and $\phi_{ij}^{q,\ell,\nu} \in [0, 2\pi]$. The fit results are,

$$Y_u = \begin{pmatrix} -1.68 - 3.37i & -0.09 + 0.03i & -0.1 - 0.02i \\ 1.53 + 4.95i & -0.57 + 0.55i & 0.48 + 0.002i \\ 0.76 + 0.18i & -1.04 + 0.46i & 0.58 - 0.65i \end{pmatrix},$$

$$Y_d = \begin{pmatrix} -4.15 + 3.58i & 2.20 - 0.89i & 2.62 - 4.20i \\ -0.33 - 0.36i & 0.07 - 0.075i & 0.17 + 0.47i \\ -0.24 - 0.07i & -0.06 - 0.084i & -0.07 - 0.12i \end{pmatrix},$$

$$Y_l = \begin{pmatrix} -0.07-0.06i & 0.099-0.004i & 0.45-0.32i \\ -0.14-0.09i & 0.08-0.06i & -0.63+0.24i \\ -0.04+0.09i & -0.09+0.06i & 0.10-0.0003i \end{pmatrix}.$$

with $\varepsilon = 0.1$, $\delta = 1.196$, and $\chi^2_{min} = 3.16$.

The $\mathscr{Z}_2 \times \mathscr{Z}_9$ model

The dimensionless coefficients $y_{ij}^{u,d,\ell,\nu} = |y_{ij}^{u,d,\ell,\nu}|e^{i\phi_{ij}^{q,\ell,\nu}}$ are scanned with $|y_{ij}^{u,d,\ell,\nu}| \in [0.9, 2\pi]$ and $\phi_{ij}^{q,\ell,\nu} \in [0, 2\pi]$. The fit results are,

$$Y_u = \begin{pmatrix} 1 & 0.87-0.49i & -0.23+0.97i \\ -0.9+1.05i & -0.7-0.72i & 1 \\ 0.94-0.33i & 0.55+0.84i & 0.9 \end{pmatrix},$$

$$Y_d = \begin{pmatrix} 0.99-0.09i & 3.24-1.05i & 1 \\ 0.99-0.10i & 0.92+0.39i & 0.9 \\ 1 & 1 & -1.04+0.54i \end{pmatrix},$$

$$Y_l = \begin{pmatrix} 0.9 & 0.9 & 1.5 \\ 0.9 & 1.5 & 1.5 \\ 1.5 & 1.5 & 0.9 \end{pmatrix}.$$

with $\varepsilon = 0.23$, $\delta = 1.196$, and $\chi^2_{min} = 5.91$.

The $\mathscr{Z}_2 \times \mathscr{Z}_{11}$ model

The dimensionless coefficients $y_{ij}^{u,d,\ell,\nu} = |y_{ij}^{u,d,\ell,\nu}| e^{i\phi_{ij}^{q,\ell,\nu}}$ are scanned with $|y_{ij}^{u,d,\ell,\nu}| \in [0.7, 2\pi]$ and $\phi_{ij}^{q,\ell,\nu} \in [0, 2\pi]$. The fit results are,

$$Y_u = \begin{pmatrix} 2.19 - 0.18i & 1.40 - 0.09i & 0.70 - 0.002i \\ 2.12 + 0.02i & -1.02 + 2.12i & 4.45 - 1.01i \\ 0.33 - 0.71i & 0.92 + 0.42i & 0.82 - 0.26i \end{pmatrix},$$

$$Y_d = \begin{pmatrix} 0.40 + 0.59i & 3.61 - 0.16i & 3.34 - 4.06i \\ 1.02 + 0.01i & -0.36 + 1.18i & 1.29 + 0.36i \\ -0.77 + 0.33i & 0.82 + 0.02i & -0.51 + 0.48i \end{pmatrix}$$

$$Y_l = \begin{pmatrix} -0.73 + 0.001i & -0.58 + 0.53i & 0.001 + 1.29i \\ 6.24 + 0.37i & 3.48 - 2.44i & 1.71 + 1.7 \times 10^{-5} i \\ 0.24 - 1.16i & -0.36 - 0.61i & -0.60 + 0.35i \end{pmatrix}$$

with $\varepsilon = 0.28$, $\delta = 1.196$, and $\chi^2_{min} = 11.82$.

The $\mathscr{Z}_8 \times \mathscr{Z}_{22}$ model

The dimensionless coefficients $y_{ij}^{u,d,\ell,\nu} = |y_{ij}^{u,d,\ell,\nu}| e^{i\phi_{ij}^{q,\ell,\nu}}$ are scanned with $|y_{ij}^{u,d,\ell,\nu}| \in [0.9, 2]$ and $\phi_{ij}^{q,\ell,\nu} \in [0, 2\pi]$. The fit results are,

$$Y_u = \begin{pmatrix} 0.12 + 1.44i & -0.38 - 0.82i & 0.989 + 0.004i \\ -1.27 - 1.38i & -0.56 + 0.82i & -1.22 - 0.24i \\ -1.12 - 0.25i & -1.12 - 0.43i & -2.70 - 2.61i \end{pmatrix},$$

$$Y_d = \begin{pmatrix} -1.36 + 0.39i & 0.31 - 1.28i & 0.71 + 0.61i \\ -1.05 + 0.27i & -0.44 + 0.85i & 0.47 - 0.79i \\ -1.11 - 0.37i & -0.81 + 0.42i & 0.80 + 0.82i \end{pmatrix}$$

$$Y_l = \begin{pmatrix} -1.40 - 0.21i & 1.14 - 0.004i & -0.78 + 0.45i \\ -0.88 + 0.16i & -0.54 + 0.78i & -1.16 + 0.11i \\ 0.85 + 0.34i & 0.899 + 0.003i & 0.899 - 0.003i \end{pmatrix}$$

with $\varepsilon = 0.23$, $\delta = 1.196$, and $\chi^2_{min} = 1.62$.

The SM background

Production mode	**Channel**	**SM Backgrounds**
Inclusive production	jet-jet	$pp \to jj$
	$\ell^+\ell^- (\ell = e, \mu, \tau)$	$pp \to \ell^+\ell^-$
	μe	$pp \to t\bar{t}, pp \to VV(V = W^+, W^-, Z)$, $pp \to \ell^+\ell^-, pp \to tWb$
	$\mu\tau, e\tau$	$pp \to$ multijets, $pp \to W+$ jets , $pp \to t\bar{t}, pp \to VV(V = W^+, W^-, Z)$, $pp \to \ell^+\ell^-, pp \to tWb$
	$b\bar{b}$	$pp \to b\bar{b}$
	$\gamma\gamma$	$pp \to \gamma\gamma$
	$t\bar{t}$	$pp \to t\bar{t}$
Associative production	$t\bar{t}a \to t\bar{t}t\bar{t}$	$pp \to t\bar{t}t\bar{t}$
	$ab\bar{b} \to \tau\tau b\bar{b}$	$pp \to \tau\tau b\bar{b}$
	$ab \to \tau\tau b$	$pp \to$ multijets, $pp \to W+$ jets, $pp \to t\bar{t}$ $pp \to \ell^+\ell^-, pp \to tWb$, $pp \to VV$
Di-flavon production	$aa \to b\bar{b}\ell\ell(\ell = \mu, \tau)$	$pp \to b\bar{b}\ell\ell$
	$aa \to b\bar{b}b\bar{b}$	$pp \to b\bar{b}b\bar{b}$

Table A.1 SM Backgrounds for the flavon production through various channels.

Benchmark points for the Yukawa couplings of the SHVM

We reproduce the fermion masses using the values of the fermion masses at 1TeV, given in equation A.3. For this, we conduct a χ^2 fit to the masses of quarks and charged leptons, as well as the parameters describing quark mixing, in the similar way as done in section A.

The dimensionless coefficients $y_{ij}^{u,d,\ell,\nu} = |y_{ij}^{u,d,\ell,\nu}| e^{i\phi_{ij}^{q,\ell,\nu}}$ are scanned with $|y_{ij}^{u,d,\ell,\nu}| \in [0.1, 4\pi]$ and $\phi_{ij}^{q,\ell,\nu} \in [0, 2\pi]$. The fit results are,

$$y_{ij}^{u} = \begin{pmatrix} 1.002 + 1.730i & 0 & 0.580 + 1.944i \\ 0 & -0.892 + 0.450i & -0.974 - 0.140i \\ 0 & -0.320 + 1.597i & 0.999 - 0.016i \end{pmatrix},$$

$$y_{ij}^{d} = \begin{pmatrix} -1.071 + 0.086i & -0.094 + 0.0897i & 0.080 - 0.086i \\ 0.554 - 0.744i & 1.212 - 0.209i & 1.211 + 0.238i \\ 0.305 + 1.978i & -1.142 + 0.139i & -1.175 - 0.019i \end{pmatrix},$$

We obtain $\delta_{\mathrm{CP}}^{q} \approx 1.144$ for Dirac CP phase.

$$y_{ij}^{\ell} = \begin{pmatrix} 0.902 - 0.093i & 0.523 - 0.887i & 0.356 - 1.041i \\ 0 & 0.295 + 2.341i & 0.422 + 1.016i \\ 0 & 0 & 3.173 + 5.834 \times 10^{-9} i \end{pmatrix},$$

The neutrino couplings for normal mass ordering are,

$$y_{ij}^{\nu} = \begin{pmatrix} 0.6 - 0.88i & 0.87 - 0.41i & 1.5 - 0.00004i \\ 0 & 0.96 + 0.12i & -0.52 - 1.41i \\ 0 & -1.43 + 0.28i & 1.5 + 0.00004i \end{pmatrix},$$

and the leptonic Dirac *CP* phase turns out to be $\delta_{\mathrm{CP}}^{\ell} \approx 3.14$.

Bi-unitary transformation matrices in SHVM

$$U_u = \begin{pmatrix} -0.973-0.233i & -4.156\times10^{-5}-9.950\times10^{-6}i & 5.064\times10^{-8}+1.213\times10^{-8}i \\ 9.075\times10^{-6}+4.175\times10^{-5}i & -0.212-0.977i & -0.002-0.010i \\ 4.858\times10^{-7}+0.000i & -0.010+0.000i & 1.000+0.000i \end{pmatrix}$$

$$V_u = \begin{pmatrix} 0.270+0.963i & -1.516\times10^{-2}-1.394\times10^{-2}i & 1.929\times10^{-3}+6.868\times10^{-3}i \\ 1.271\times10^{-2}+1.620\times10^{-2}i & 0.939+0.344i & -2.806\times10^{-4}-2.064\times10^{-5}i \\ -7.129\times10^{-3}+0.000i & 3.955\times10^{-4}+0.000i & 1.000+0.000i \end{pmatrix}$$

$$U_d = \begin{pmatrix} -8.408\times10^{-2}-8.859\times10^{-2}i & -2.487\times10^{-1}+5.717\times10^{-1}i & 1.301\times10^{-1}-7.613\times10^{-1}i \\ -6.040\times10^{-1}-2.561\times10^{-1}i & -5.112\times10^{-1}-3.329\times10^{-1}i & -4.401\times10^{-1}-6.160\times10^{-2}i \\ 7.449\times10^{-1}+0.000i & -4.891\times10^{-1}+0.000i & -4.540\times10^{-1}+0.000i \end{pmatrix}$$

$$V_d = \begin{pmatrix} -4.824\times10^{-1}+8.635\times10^{-1}i & 1.107\times10^{-1}-9.716\times10^{-2}i & -2.149\times10^{-4}+3.632\times10^{-3}i \\ -1.471\times10^{-1}-2.873\times10^{-3}i & -9.248\times10^{-1}-3.493\times10^{-1}i & -3.088\times10^{-2}-1.125\times10^{-2}i \\ -7.820\times10^{-3}+0.000i & -3.213\times10^{-2}+0.000i & 9.995\times10^{-1}+0.000i \end{pmatrix}$$

$$U_\ell = \begin{pmatrix} -1.457\times10^{-1}-9.893\times10^{-1}i & -1.572\times10^{-4}+4.160\times10^{-4}i & 3.416\times10^{-6}-7.407\times10^{-6}i \\ -3.177\times10^{-4}+3.113\times10^{-4}i & -9.642\times10^{-1}+2.645\times10^{-1}i & 1.989\times10^{-2}-5.455\times10^{-3}i \\ 1.188\times10^{-6}+0.000i & 2.062\times10^{-2}+0.000i & 9.998\times10^{-1}+0.000i \end{pmatrix}$$

$$V_\ell = \begin{pmatrix} -2.455\times10^{-1}-9.644\times10^{-1}i & -2.395\times10^{-2}+9.067\times10^{-2}i & 9.415\times10^{-3}-2.756\times10^{-2}i \\ -7.731\times10^{-2}-6.040\times10^{-2}i & -3.598\times10^{-1}-8.677\times10^{-1}i & 1.260\times10^{-1}+3.034\times10^{-1}i \\ 4.024\times10^{-3}+0.000i & 3.298\times10^{-1}+0.000i & 9.440\times10^{-1}+0.000i \end{pmatrix}$$

Scalar mass matrix diagonalization in SHVM

$$m_s^2 = \lambda_\chi \Lambda^2 \begin{pmatrix} 16\varepsilon_7^2 & 8\varepsilon_1\varepsilon_7 & 8\varepsilon_4\varepsilon_7 & 8\varepsilon_5\varepsilon_7 & 8\varepsilon_2\varepsilon_7 & 8\varepsilon_6\varepsilon_7 & 8\varepsilon_3\varepsilon_7 \\ 8\varepsilon_1\varepsilon_7 & 16\varepsilon_1^2 & 8\varepsilon_1\varepsilon_4 & 8\varepsilon_1\varepsilon_5 & 8\varepsilon_1\varepsilon_2 & 8\varepsilon_1\varepsilon_6 & 8\varepsilon_1\varepsilon_3 \\ 8\varepsilon_4\varepsilon_7 & 8\varepsilon_1\varepsilon_4 & 16\varepsilon_4^2 & 8\varepsilon_4\varepsilon_5 & 8\varepsilon_2\varepsilon_4 & 8\varepsilon_4\varepsilon_6 & 8\varepsilon_3\varepsilon_4 \\ 8\varepsilon_5\varepsilon_7 & 8\varepsilon_1\varepsilon_5 & 8\varepsilon_4\varepsilon_5 & 16\varepsilon_5^2 & 8\varepsilon_2\varepsilon_5 & 8\varepsilon_5\varepsilon_6 & 8\varepsilon_3\varepsilon_5 \\ 8\varepsilon_2\varepsilon_7 & 8\varepsilon_1\varepsilon_2 & 8\varepsilon_2\varepsilon_4 & 8\varepsilon_2\varepsilon_5 & 16\varepsilon_2^2 & 8\varepsilon_2\varepsilon_6 & 8\varepsilon_2\varepsilon_3 \\ 8\varepsilon_6\varepsilon_7 & 8\varepsilon_1\varepsilon_6 & 8\varepsilon_4\varepsilon_6 & 8\varepsilon_5\varepsilon_6 & 8\varepsilon_2\varepsilon_6 & 16\varepsilon_6^2 & 8\varepsilon_3\varepsilon_6 \\ 8\varepsilon_3\varepsilon_7 & 8\varepsilon_1\varepsilon_3 & 8\varepsilon_3\varepsilon_4 & 8\varepsilon_3\varepsilon_5 & 8\varepsilon_2\varepsilon_3 & 8\varepsilon_3\varepsilon_6 & 16\varepsilon_3^2 \end{pmatrix},$$

$$U = \begin{pmatrix} 1 & -3.24\times10^{-4} & -1.94\times10^{-6} & -5.34\times10^{-7} & -4.88\times10^{-8} & 4.69\times10^{-8} & 4.14\times10^{-10} \\ -3.24\times10^{-4} & -0.999 & -8.56\times10^{-3} & -2.35\times10^{-3} & -2.15\times10^{-4} & 2.06\times10^{-4} & 1.82\times10^{-6} \\ -1.68\times10^{-6} & 8.66\times10^{-3} & -0.999 & -4.73\times10^{-2} & -4.18\times10^{-3} & 3.98\times10^{-3} & 3.52\times10^{-4} \\ -3.79\times10^{-7} & 1.95\times10^{-2} & 4.75\times10^{-2} & -0.998 & -1.85\times10^{-2} & 1.77\times10^{-2} & 1.56\times10^{-4} \\ -3.37\times10^{-8} & 1.73\times10^{-4} & 3.95\times10^{-3} & 2.25\times10^{-2} & -0.968 & 2.49\times10^{-1} & 1.76\times10^{-3} \\ -1.89\times10^{-8} & 9.75\times10^{-5} & 2.23\times10^{-3} & 1.26\times10^{-2} & 2.499\times10^{-1} & 0.97 & 3.12\times10^{-3} \\ -1.18\times10^{-10} & 6.08\times10^{-7} & 1.39\times10^{-5} & 7.84\times10^{-4} & 9.27\times10^{-4} & -3.46\times10^{-3} & 0.999 \end{pmatrix}$$

$$M_{dia}^2 = \lambda_\chi \Lambda^2 \mathrm{dia}\Big(4.71\times10^{-18}, 9.33\times10^{-11}, 3.56\times10^{-8}, 7.30\times10^{-7}, 9.45\times10^{-5}, 3.67\times10^{-4}, 12.01\Big).$$