Charged current $b \to c\tau\bar{\nu}_\tau$ anomalies in a general W' boson scenario

Eduardo Rojas Peña
Universidad de Nariño, Pasto, Colombia

collaborators: Néstor Quintero and John D. Gómez

MOCa: Materia Oscura en Colombia

30 de septiembre de 2019, Universidad de los andes, Bogotá, Colombia

Eduardo Rojas Peña
Universidad de Nariño, Pasto, Colombia
collaborators: Néstor Quintero and John D. Gómez

Experimental status on observables related to the charged transition $b \to c\tau\bar{\nu}_\tau$.

Eduardo Rojas Peña
Universidad de Nariño, Pasto, Colombia
collaborators: Néstor Quintero and John D. Gómez

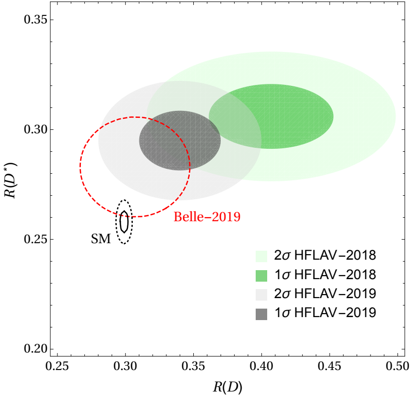
Observable	Exp measurement	SM prediction
$R(D)$	$0.307 \pm 0.037 \pm 0.016$ Belle-2019 [1]	0.299 ± 0.003 [2, 3]
	$0.340 \pm 0.027 \pm 0.013$ HFLAV [2]	
$R(D^*)$	$0.283 \pm 0.018 \pm 0.014$ Belle-2019 [1]	0.258 ± 0.005 [2, 3]
	$0.295 \pm 0.011 \pm 0.008$ HFLAV [2]	
$R(J/\psi)$	$0.71 \pm 0.17 \pm 0.18$ [4]	0.283 ± 0.048 [5]
$P_\tau(D^*)$	$-0.38 \pm 0.51^{+0.21}_{-0.16}$ [6, 7]	-0.497 ± 0.013 [8]
$F_L(D^*)$	$0.60 \pm 0.08 \pm 0.035$ [9]	0.46 ± 0.04 [10]
$R(X_c)$	0.223 ± 0.030 [11]	0.216 ± 0.003 [11]

where

$$R(D^{(*)}) = \frac{\mathrm{BR}(B \to D^{(*)}\tau\bar{\nu}_\tau)}{\mathrm{BR}(B \to D^{(*)}\ell'\bar{\nu}_{\ell'})}, \quad \ell' = e \text{ or } \mu, \tag{1}$$

Índice
The $R(D)$ and $R(D^*)$ anomalies
Most general

The HFLAV-2018 and HFLAV-2019 averages (green and gray region, respectively)



Eduardo Rojas Peña
Universidad de Nariño, Pasto, Colombia
collaborators: Néstor Quintero and John D. Gómez

Most general Lorentz invariant Lagrangian

$$\mathcal{L}_{W'} = \frac{W'_\mu}{\sqrt{2}} \left[\bar{u}_i (\epsilon^L_{u_i d_j} P_L + \epsilon^R_{u_i d_j} P_R) \gamma^\mu d_j + \bar{\ell}_i (\epsilon^L_{\ell_i \nu_j} P_L + \epsilon^R_{\ell_i \nu_j} P_R) \gamma^\mu \nu_j \right] + \mathrm{h.c.}, \quad (2)$$

New Physics (NP) scenarios

- charged scalars [12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28],
- leptoquarks (both scalar and vector) [29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 31, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62],
- extra gauge bosons [13, 63, 64, 65, 66, 67, 68, 59, 69, 70, 71, 72, 73, 74, 75, 76],
- right-handed neutrinos [28, 71, 72, 73, 74, 75, 76, 77, 78],
- R-parity violating (RPV) supersymmetric couplings [8, 79, 80, 81, 82, 83, 84, 85];

The goodness of fit for low energy W' models

		pull$_i$								best-fit point			
	parameters on	$R(D)$	$R(D^*)$	$R(J/\psi)$	$P_\tau(D^*)$	$F_L(D^*)$	$R(X_c)$	BR$(B_c \to \tau\bar{\nu})$	χ^2_{min}	ϵ^L_{cb}	ϵ^R_{cb}	$\epsilon^L_{\tau\nu}$	$\epsilon^R_{\tau\nu}$
*	$(\epsilon^L_{cb}, \epsilon^L_{\tau\nu})$	-0.047	0.028	1.53	0.21	1.46	-0.93	-0.27	5.49	-0.340	—	-0.280	—
	$(\epsilon^L_{cb}, \epsilon^R_{\tau\nu})$	-0.050	0.023	1.53	-0.013	1.46	-0.94	-0.27	5.44	0.544	—	—	0.963
2P	$(\epsilon^R_{cb}, \epsilon^L_{\tau\nu})$	2.38	0.81	1.58	0.17	1.61	-0.059	-0.26	11.48	—	-0.252	0.289	—
	$(\epsilon^R_{cb}, \epsilon^R_{\tau\nu})$	-0.050	0.023	1.53	-0.013	1.46	-0.94	-0.27	5.44	—	0.544	—	0.963
*	$(\epsilon^L_{cb}, \epsilon^R_{cb}, \epsilon^L_{\tau\nu})$	0.27	-0.15	1.52	0.22	1.41	-0.91	-0.27	5.35	0.272	-0.044	0.326	—
3P	$(\epsilon^R_{cb}, \epsilon^L_{\tau\nu}, \epsilon^R_{\tau\nu})$	0.27	-0.15	1.52	0.011	1.41	-0.91	-0.27	5.31	—	0.498	-0.031	1.014
	$(\epsilon^L_{cb}, \epsilon^L_{\tau\nu}, \epsilon^R_{\tau\nu})$	-0.050	0.023	1.53	-7.4×10^{-7}	1.46	-0.94	-0.27	5.44	0.558	—	0.010	0.911
4P	$(\epsilon^L_{cb}, \epsilon^R_{cb}, \epsilon^L_{\tau\nu}, \epsilon^R_{\tau\nu})$	0.27	-0.15	1.52	-4.1×10^{-6}	1.41	-0.91	-0.27	5.31	1.120	-0.098	0.007	-0.428

Table: For a gauge boson mass $M_{W'} = 1$ TeV. All 2P models have an acceptable value for $\chi^2_{\mathrm{min}}/\mathrm{dof} \sim 1$ except the model with RH coupling to quarks and LH coupling to leptons.

The 95% CL allowed parameter space in the $(\epsilon^L_{cb}, \epsilon^L_{\tau\nu_\tau})$ plane for (a) $M_{W'} = 0.5$ TeV and (b) $M_{W'} = 1$ TeV

Eduardo Rojas Peña
Universidad de Nariño, Pasto, Colombia
collaborators: Néstor Quintero and John D. Gómez

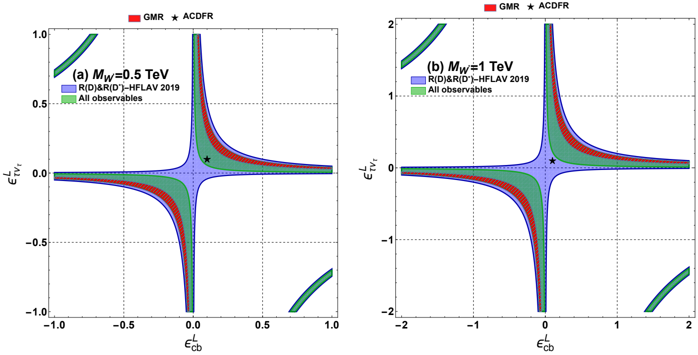


Figure: The purple region is obtained by considering only $R(D^{(*)})$ from HFLAV-2019 average, while the green one is obtained by taking into account all the $b \to c\tau\bar{\nu}_\tau$ observables. The black star and red hatched region represent the ACDFR model [69] and GMR analysis [70], respectively.

The 95% CL allowed parameter space in the $(\epsilon^R_{cb}, \epsilon^R_{\tau\nu_\tau})$ plane for (a) $M_{W'} = 1$ TeV and (b) $M_{W'} = 1.2$ TeV.

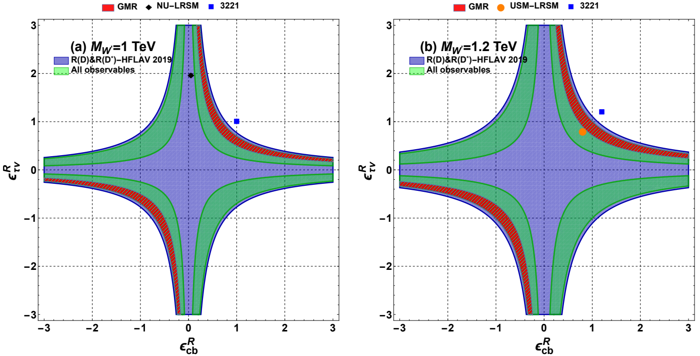


Figure: The purple region is obtained by considering only $R(D^{(*)})$ from HFLAV-2019 averages, while the green one is obtained by taking into account all the $b \to c\tau\bar{\nu}_\tau$ observables. The black diamond, blue squared, red hatche [30] region, and orange circle represent the NU-LRSM model [64, 65], 3321 gauge model [73, 74], GMR analysis [70], and USM-LRSM [72], respectively.

the dark matter connection?

Eduardo Rojas Peña
Universidad de Nariño, Pasto, Colombia
collaborators: Néstor Quintero and John D. Gómez

- A theory of R(D*, D) anomaly with right-handed current [86]
- Reconciling B-decay anomalies with neutrino masses, dark matter and constraints from flavour violation [30]
- B-physics anomalies: The bridge between R-parity violating Supersymmetry and flavoured Dark Matter [87]

Conclusions

Eduardo Rojas Peña
Universidad de Nariño, Pasto, Colombia
collaborators: Néstor Quintero and John D. Gómez

- Motivated by the new HFLAV world average values on the ratios $R(D^{(*)})$, due to the recent Belle measurements, we addressed the anomalies $R(D^{(*)})$ related to the charged current transition $b \to c\tau\bar{\nu}_\tau$ within a general W' boson scenario.In order to provide a robust analysis, we considered in addition the available experimental information on all the charged transition $b \to c\tau\bar{\nu}_\tau$ observables, namely the ratios $R(J/\psi)$, $R(X_c)$, polarizations $P_\tau(D^*), F_L(D^*)$, as well as the upper limit $\mathrm{BR}(B_c^- \to \tau^-\bar{\nu}_\tau) < 10\%$.
- We have carried out a model-independent study based on the most general effective Lagrangian given in terms of the flavor-dependent couplings $\epsilon_{cb}^{L,R}$ and $\epsilon_{\tau\nu_\tau}^{L,R}$ of the currents $\bar{c}\gamma_\mu P_{L,R} b$ and $\bar{\tau}\gamma^\mu P_{L,R}\nu_\tau$, that yields to a tree-level effective contribution generated by a general W' boson. With the above mentioned observables, we performed a χ^2 analysis by considering the cases of two, three and four nonzero $\epsilon_{cb}^{L,R}$ and $\epsilon_{\tau\nu_\tau}^{L,R}$ couplings (with different chiral charges), referred to as 2P, 3P and 4P models, respectively. It is found that the 2P models represent the best candidate to adjust the experimental charged current B anomalies.

Eduardo Rojas Peña
Universidad de Nariño, Pasto, Colombia
collaborators: Néstor Quintero and John D. Gómez

Gracias

References I

A. Abdesselam *et al.* [Belle Collaboration], arXiv:1904.08794 [hep-ex].

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

*** Non-standard form, no INSPIRE lookup performed ***

R. Aaij *et al.* [LHCb Collaboration], Phys. Rev. Lett. **120**, no. 12, 121801 (2018) doi:10.1103/PhysRevLett.120.121801 [arXiv:1711.05623 [hep-ex]].

R. Watanabe, Phys. Lett. B **776**, 5 (2018) doi:10.1016/j.physletb.2017.11.016 [arXiv:1709.08644 [hep-ph]].

References II

- S. Hirose *et al.* [Belle Collaboration], Phys. Rev. D **97**, no. 1, 012004 (2018) doi:10.1103/PhysRevD.97.012004 [arXiv:1709.00129 [hep-ex]].
- S. Hirose *et al.* [Belle Collaboration], Phys. Rev. Lett. **118**, no. 21, 211801 (2017) doi:10.1103/PhysRevLett.118.211801 [arXiv:1612.00529 [hep-ex]].
- M. Tanaka and R. Watanabe, Phys. Rev. D **87**, no. 3, 034028 (2013) doi:10.1103/PhysRevD.87.034028 [arXiv:1212.1878 [hep-ph]].
- A. Abdesselam *et al.* [Belle Collaboration], arXiv:1903.03102 [hep-ex].

Eduardo Rojas Peña
Universidad de Nariño, Pasto, Colombia
collaborators: Néstor Quintero and John D. Gómez

Eduardo Rojas Peña
Universidad de Nariño, Pasto, Colombia
collaborators: Néstor Quintero and John D. Gómez

References III

- A. K. Alok, D. Kumar, S. Kumbhakar and S. U. Sankar, Phys. Rev. D **95**, no. 11, 115038 (2017) doi:10.1103/PhysRevD.95.115038 [arXiv:1606.03164 [hep-ph]].
- S. Kamali, Int. J. Mod. Phys. A **34**, no. 06n07, 1950036 (2019) doi:10.1142/S0217751X19500362 [arXiv:1811.07393 [hep-ph]].
- A. Biswas, D. K. Ghosh, S. K. Patra and A. Shaw, Int. J. Mod. Phys. A **34**, no. 21, 1950112 (2019) doi:10.1142/S0217751X19501124 [arXiv:1801.03375 [hep-ph]].

References IV

S. Iguro, Y. Omura and M. Takeuchi, Phys. Rev. D **99**, no. 7, 075013 (2019) doi:10.1103/PhysRevD.99.075013 [arXiv:1810.05843 [hep-ph]].

S. Fraser, C. Marzo, L. Marzola, M. Raidal and C. Spethmann, Phys. Rev. D **98**, no. 3, 035016 (2018) doi:10.1103/PhysRevD.98.035016 [arXiv:1805.08189 [hep-ph]].

R. Martinez, C. F. Sierra and G. Valencia, Phys. Rev. D **98**, no. 11, 115012 (2018) doi:10.1103/PhysRevD.98.115012 [arXiv:1805.04098 [hep-ph]].

L. Dhargyal, Phys. Rev. D **93**, no. 11, 115009 (2016) doi:10.1103/PhysRevD.93.115009 [arXiv:1605.02794 [hep-ph]].

References V

- A. Crivellin, J. Heeck and P. Stoffer, Phys. Rev. Lett. **116**, no. 8, 081801 (2016) doi:10.1103/PhysRevLett.116.081801 [arXiv:1507.07567 [hep-ph]].
- S. Iguro and K. Tobe, Nucl. Phys. B **925**, 560 (2017) doi:10.1016/j.nuclphysb.2017.10.014 [arXiv:1708.06176 [hep-ph]].
- M. Wei and Y. Chong-Xing, Phys. Rev. D **95**, no. 3, 035040 (2017) doi:10.1103/PhysRevD.95.035040 [arXiv:1702.01255 [hep-ph]].
- A. Celis, M. Jung, X. Q. Li and A. Pich, Phys. Lett. B **771**, 168 (2017) doi:10.1016/j.physletb.2017.05.037 [arXiv:1612.07757 [hep-ph]].

Eduardo Rojas Peña
Universidad de Nariño, Pasto, Colombia
collaborators: Néstor Quintero and John D. Gómez

Eduardo Rojas Peña
Universidad de Nariño, Pasto, Colombia
collaborators: Néstor Quintero and John D. Gómez

References VI

- C. H. Chen and T. Nomura, Eur. Phys. J. C **77**, no. 9, 631 (2017) doi:10.1140/epjc/s10052-017-5198-6 [arXiv:1703.03646 [hep-ph]].
- Y. Sakaki and H. Tanaka, Phys. Rev. D **87**, no. 5, 054002 (2013) doi:10.1103/PhysRevD.87.054002 [arXiv:1205.4908 [hep-ph]].
- A. Crivellin, C. Greub and A. Kokulu, Phys. Rev. D **86**, 054014 (2012) doi:10.1103/PhysRevD.86.054014 [arXiv:1206.2634 [hep-ph]].
- A. Crivellin, A. Kokulu and C. Greub, Phys. Rev. D **87**, no. 9, 094031 (2013) doi:10.1103/PhysRevD.87.094031 [arXiv:1303.5877 [hep-ph]].

References VII

A. Celis, M. Jung, X. Q. Li and A. Pich, JHEP **1301**, 054 (2013) doi:10.1007/JHEP01(2013)054 [arXiv:1210.8443 [hep-ph]].

P. Ko, Y. Omura and C. Yu, JHEP **1303**, 151 (2013) doi:10.1007/JHEP03(2013)151 [arXiv:1212.4607 [hep-ph]].

P. Ko, Y. Omura, Y. Shigekami and C. Yu, Phys. Rev. D **95**, no. 11, 115040 (2017) doi:10.1103/PhysRevD.95.115040 [arXiv:1702.08666 [hep-ph]].

S. P. Li, X. Q. Li, Y. D. Yang and X. Zhang, JHEP **1809**, 149 (2018) doi:10.1007/JHEP09(2018)149 [arXiv:1807.08530 [hep-ph]].

References VIII

C. Hati, J. Kriewald, J. Orloff and A. M. Teixeira, arXiv:1907.05511 [hep-ph].

C. Hati, G. Kumar, J. Orloff and A. M. Teixeira, JHEP **1811**, 011 (2018) doi:10.1007/JHEP11(2018)011 [arXiv:1806.10146 [hep-ph]].

N. Assad, B. Fornal and B. Grinstein, Phys. Lett. B **777**, 324 (2018) doi:10.1016/j.physletb.2017.12.042 [arXiv:1708.06350 [hep-ph]].

B. Fornal, S. A. Gadam and B. Grinstein, Phys. Rev. D **99**, no. 5, 055025 (2019) doi:10.1103/PhysRevD.99.055025 [arXiv:1812.01603 [hep-ph]].

References IX

H. Yan, Y. D. Yang and X. B. Yuan, Chin. Phys. C **43**, no. 8, 083105 (2019) doi:10.1088/1674-1137/43/8/083105 [arXiv:1905.01795 [hep-ph]].

C. Cornella, J. Fuentes-Martin and G. Isidori, JHEP **1907**, 168 (2019) doi:10.1007/JHEP07(2019)168 [arXiv:1903.11517 [hep-ph]].

D. Bečirević, S. Fajfer, N. Košnik and O. Sumensari, Phys. Rev. D **94**, no. 11, 115021 (2016) doi:10.1103/PhysRevD.94.115021 [arXiv:1608.08501 [hep-ph]].

Eduardo Rojas Peña Universidad de Nariño, Pasto, Colombia collaborators: Néstor Quintero and John D. Gómez

References X

D. Bečirević, I. Doršner, S. Fajfer, N. Košnik, D. A. Faroughy and O. Sumensari, Phys. Rev. D **98**, no. 5, 055003 (2018) doi:10.1103/PhysRevD.98.055003 [arXiv:1806.05689 [hep-ph]].

R. Alonso, B. Grinstein and J. Martin Camalich, JHEP **1510**, 184 (2015) doi:10.1007/JHEP10(2015)184 [arXiv:1505.05164 [hep-ph]].

L. Calibbi, A. Crivellin and T. Ota, Phys. Rev. Lett. **115**, 181801 (2015) doi:10.1103/PhysRevLett.115.181801 [arXiv:1506.02661 [hep-ph]].

S. Fajfer and N. Košnik, Phys. Lett. B **755**, 270 (2016) doi:10.1016/j.physletb.2016.02.018 [arXiv:1511.06024 [hep-ph]].

References XI

- R. Barbieri, G. Isidori, A. Pattori and F. Senia, Eur. Phys. J. C **76**, no. 2, 67 (2016) doi:10.1140/epjc/s10052-016-3905-3 [arXiv:1512.01560 [hep-ph]].
- R. Barbieri, C. W. Murphy and F. Senia, Eur. Phys. J. C **77**, no. 1, 8 (2017) doi:10.1140/epjc/s10052-016-4578-7 [arXiv:1611.04930 [hep-ph]].
- G. Hiller, D. Loose and K. Schönwald, JHEP **1612**, 027 (2016) doi:10.1007/JHEP12(2016)027 [arXiv:1609.08895 [hep-ph]].

Eduardo Rojas Peña
Universidad de Nariño, Pasto, Colombia
collaborators: Néstor Quintero and John D. Gómez

References XII

B. Bhattacharya, A. Datta, J. P. Guévin, D. London and R. Watanabe, JHEP **1701**, 015 (2017) doi:10.1007/JHEP01(2017)015 [arXiv:1609.09078 [hep-ph]].

D. Buttazzo, A. Greljo, G. Isidori and D. Marzocca, JHEP **1711**, 044 (2017) doi:10.1007/JHEP11(2017)044 [arXiv:1706.07808 [hep-ph]].

J. Kumar, D. London and R. Watanabe, Phys. Rev. D **99**, no. 1, 015007 (2019) doi:10.1103/PhysRevD.99.015007 [arXiv:1806.07403 [hep-ph]].

L. Di Luzio, A. Greljo and M. Nardecchia, Phys. Rev. D **96**, no. 11, 115011 (2017) doi:10.1103/PhysRevD.96.115011 [arXiv:1708.08450 [hep-ph]].

References XIII

- L. Calibbi, A. Crivellin and T. Li, Phys. Rev. D **98**, no. 11, 115002 (2018) doi:10.1103/PhysRevD.98.115002 [arXiv:1709.00692 [hep-ph]].
- R. Barbieri and A. Tesi, Eur. Phys. J. C **78**, no. 3, 193 (2018) doi:10.1140/epjc/s10052-018-5680-9 [arXiv:1712.06844 [hep-ph]].
- M. Blanke and A. Crivellin, Phys. Rev. Lett. **121**, no. 1, 011801 (2018) doi:10.1103/PhysRevLett.121.011801 [arXiv:1801.07256 [hep-ph]].
- A. Greljo and B. A. Stefanek, Phys. Lett. B **782**, 131 (2018) doi:10.1016/j.physletb.2018.05.033 [arXiv:1802.04274 [hep-ph]].

References XIV

Eduardo Rojas Peña
Universidad de Nariño, Pasto, Colombia
collaborators: Néstor Quintero and John D. Gómez

- M. Bauer and M. Neubert, Phys. Rev. Lett. **116**, no. 14, 141802 (2016) doi:10.1103/PhysRevLett.116.141802 [arXiv:1511.01900 [hep-ph]].
- M. Bordone, C. Cornella, J. Fuentes-Martín and G. Isidori, JHEP **1810**, 148 (2018) doi:10.1007/JHEP10(2018)148 [arXiv:1805.09328 [hep-ph]].
- A. Crivellin, C. Greub, D. Müller and F. Saturnino, Phys. Rev. Lett. **122**, no. 1, 011805 (2019) doi:10.1103/PhysRevLett.122.011805 [arXiv:1807.02068 [hep-ph]].

References XV

- L. Di Luzio, J. Fuentes-Martin, A. Greljo, M. Nardecchia and S. Renner, JHEP **1811**, 081 (2018) doi:10.1007/JHEP11(2018)081 [arXiv:1808.00942 [hep-ph]].
- Y. Cai, J. Gargalionis, M. A. Schmidt and R. R. Volkas, JHEP **1710**, 047 (2017) doi:10.1007/JHEP10(2017)047 [arXiv:1704.05849 [hep-ph]].
- A. Crivellin, D. Müller and T. Ota, JHEP **1709**, 040 (2017) doi:10.1007/JHEP09(2017)040 [arXiv:1703.09226 [hep-ph]].
- X. Q. Li, Y. D. Yang and X. Zhang, JHEP **1608**, 054 (2016) doi:10.1007/JHEP08(2016)054 [arXiv:1605.09308 [hep-ph]].

References XVI

- D. Das, C. Hati, G. Kumar and N. Mahajan, Phys. Rev. D **94**, 055034 (2016) doi:10.1103/PhysRevD.94.055034 [arXiv:1605.06313 [hep-ph]].
- D. A. Faroughy, A. Greljo and J. F. Kamenik, Phys. Lett. B **764**, 126 (2017) doi:10.1016/j.physletb.2016.11.011 [arXiv:1609.07138 [hep-ph]].
- S. Sahoo, R. Mohanta and A. K. Giri, Phys. Rev. D **95**, no. 3, 035027 (2017) doi:10.1103/PhysRevD.95.035027 [arXiv:1609.04367 [hep-ph]].
- C. H. Chen, T. Nomura and H. Okada, Phys. Lett. B **774**, 456 (2017) doi:10.1016/j.physletb.2017.10.005 [arXiv:1703.03251 [hep-ph]].

References XVII

- Y. Sakaki, M. Tanaka, A. Tayduganov and R. Watanabe, Phys. Rev. D **88**, no. 9, 094012 (2013) doi:10.1103/PhysRevD.88.094012 [arXiv:1309.0301 [hep-ph]].
- S. Dasgupta, U. K. Dey, T. Jha and T. S. Ray, Phys. Rev. D **98**, no. 5, 055006 (2018) doi:10.1103/PhysRevD.98.055006 [arXiv:1801.09722 [hep-ph]].
- X. G. He and G. Valencia, Phys. Rev. D **87**, no. 1, 014014 (2013) doi:10.1103/PhysRevD.87.014014 [arXiv:1211.0348 [hep-ph]].

References XVIII

Eduardo Rojas Peña
Universidad de Nariño, Pasto, Colombia
collaborators: Néstor Quintero and John D. Gómez

- X. G. He and G. Valencia, Phys. Lett. B **779**, 52 (2018) doi:10.1016/j.physletb.2018.01.073 [arXiv:1711.09525 [hep-ph]].
- S. M. Boucenna, A. Celis, J. Fuentes-Martin, A. Vicente and J. Virto, JHEP **1612**, 059 (2016) doi:10.1007/JHEP12(2016)059 [arXiv:1608.01349 [hep-ph]].
- S. M. Boucenna, A. Celis, J. Fuentes-Martin, A. Vicente and J. Virto, Phys. Lett. B **760**, 214 (2016) doi:10.1016/j.physletb.2016.06.067 [arXiv:1604.03088 [hep-ph]].

References XIX

A. Greljo, G. Isidori and D. Marzocca, JHEP **1507**, 142 (2015) doi:10.1007/JHEP07(2015)142 [arXiv:1506.01705 [hep-ph]].

M. Abdullah, J. Calle, B. Dutta, A. Flórez and D. Restrepo, Phys. Rev. D **98**, no. 5, 055016 (2018) doi:10.1103/PhysRevD.98.055016 [arXiv:1805.01869 [hep-ph]].

A. Greljo, J. Martin Camalich and J. D. Ruiz-Álvarez, Phys. Rev. Lett. **122**, no. 13, 131803 (2019) doi:10.1103/PhysRevLett.122.131803 [arXiv:1811.07920 [hep-ph]].

References XX

- M. Carena, E. Megías, M. Quíros and C. Wagner, JHEP **1812**, 043 (2018) doi:10.1007/JHEP12(2018)043 [arXiv:1809.01107 [hep-ph]].
- K. S. Babu, B. Dutta and R. N. Mohapatra, JHEP **1901**, 168 (2019) doi:10.1007/JHEP01(2019)168 [arXiv:1811.04496 [hep-ph]].
- P. Asadi, M. R. Buckley and D. Shih, JHEP **1809**, 010 (2018) doi:10.1007/JHEP09(2018)010 [arXiv:1804.04135 [hep-ph]].
- A. Greljo, D. J. Robinson, B. Shakya and J. Zupan, JHEP **1809**, 169 (2018) doi:10.1007/JHEP09(2018)169 [arXiv:1804.04642 [hep-ph]].

References XXI

D. J. Robinson, B. Shakya and J. Zupan, JHEP **1902**, 119 (2019) doi:10.1007/JHEP02(2019)119 [arXiv:1807.04753 [hep-ph]].

P. Asadi, M. R. Buckley and D. Shih, Phys. Rev. D **99**, no. 3, 035015 (2019) doi:10.1103/PhysRevD.99.035015 [arXiv:1810.06597 [hep-ph]].

A. Azatov, D. Barducci, D. Ghosh, D. Marzocca and L. Ubaldi, JHEP **1810**, 092 (2018) doi:10.1007/JHEP10(2018)092 [arXiv:1807.10745 [hep-ph]].

References XXII

G. Cvetič, F. Halzen, C. S. Kim and S. Oh, Chin. Phys. C **41**, no. 11, 113102 (2017) doi:10.1088/1674-1137/41/11/113102 [arXiv:1702.04335 [hep-ph]].

W. Altmannshofer, P. S. Bhupal Dev and A. Soni, Phys. Rev. D **96**, no. 9, 095010 (2017) doi:10.1103/PhysRevD.96.095010 [arXiv:1704.06659 [hep-ph]].

*** Not Found with lookup: '035$_{a}$:*Deshpande*:2016*cpw*'

N. G. Deshpande and A. Menon, JHEP **1301**, 025 (2013) doi:10.1007/JHEP01(2013)025 [arXiv:1208.4134 [hep-ph]].

References XXIII

J. Zhu, H. M. Gan, R. M. Wang, Y. Y. Fan, Q. Chang and Y. G. Xu, Phys. Rev. D **93**, no. 9, 094023 (2016) doi:10.1103/PhysRevD.93.094023 [arXiv:1602.06491 [hep-ph]].

J. Zhu, B. Wei, J. H. Sheng, R. M. Wang, Y. Gao and G. R. Lu, Nucl. Phys. B **934**, 380 (2018) doi:10.1016/j.nuclphysb.2018.07.011 [arXiv:1801.00917 [hep-ph]].

Q. Y. Hu, X. Q. Li, Y. Muramatsu and Y. D. Yang, Phys. Rev. D **99**, no. 1, 015008 (2019) doi:10.1103/PhysRevD.99.015008 [arXiv:1808.01419 [hep-ph]].

S. Trifinopoulos, Eur. Phys. J. C **78**, no. 10, 803 (2018) doi:10.1140/epjc/s10052-018-6280-4 [arXiv:1807.01638 [hep-ph]].

References XXIV

*** Not Found with lookup: '035$_{a:Babu:2018vr'}$

S. Trifinopoulos, arXiv:1904.12940 [hep-ph].