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Horizontal gauge symmetries and the LHC flavour anomalies

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Outline:

- Introduction: LHC flavor anomalies and $L_\mu - L_\tau$
- 1HDM with gauged $L_\mu - L_\tau$ and vector-quarks
  - $B \to K^* \mu^+ \mu^-$
  - $B \to K \mu^+ \mu^- / B \to K e^+ e^-$
- 2HDM with gauged $L_\mu - L_\tau$ and vector- quarks
  - $h \to \tau\mu$ and $\tau \to \mu\mu\mu$
- 2HDM and 3HDM with gauged horizontal charged (no vector-quarks)
- Conclusions

Based on: Andreas Crivellin, Giancarlo D'Ambrosio and Julian Heeck

Explaining $B \to K^*\mu\mu$, $B \to K\mu\mu / B \to Kee$ and $h \to \tau\mu$ in a two-Higgs-doublet model with gauged L_μ-L_τ

arXiv:1501.00993

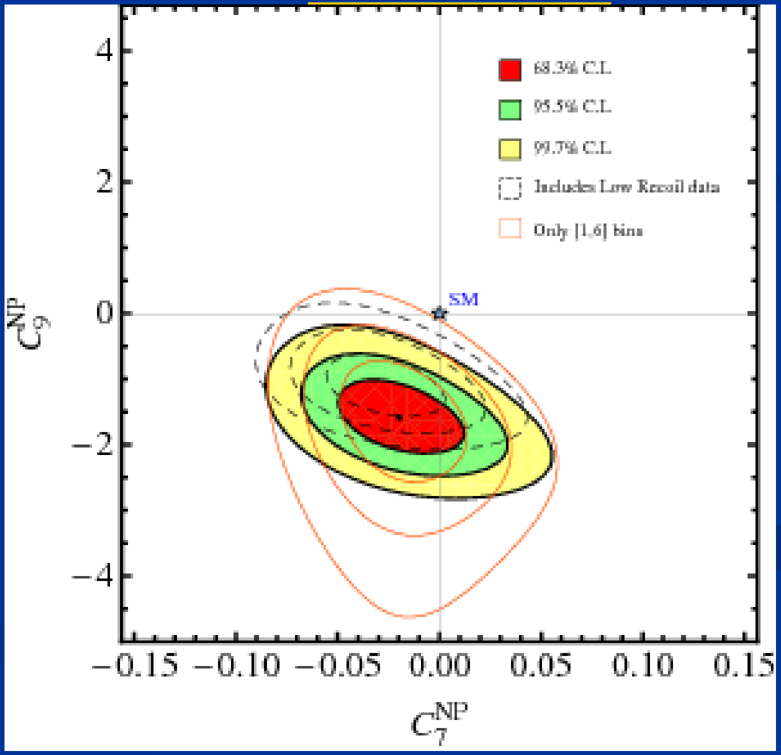
Adressing the LHC flavour anomalies with horizontal gauge symmetires (in preperation)

The LHC flavour anomalies

$B \to K^*\mu\mu$

- 2-3 σ deviation from the SM mostly in C5’
- Can be explained by $O_9 = \bar{s}\gamma^\mu P_L b \bar{\ell}\gamma_\mu \ell$
  Descotes-Genon et al. 1307.5683, Altmannshofer and DS 1308.1501, Beaujean et al. 1310.2478
- New physics explanation is not easy
  (MSSM, 2HDM, extra dimensions not possible).
- Most natural explanation: Z’
  Gauld et al. 1310.1082,
  Buras et al. 1311.6729, …
- Subleading hadronic effects might be larger than expected…

arXiv:1307.5683



R(K) = B→Kμμ/B→Kee

- Lepton flavour universality violation
- 2.6 σ deviation from the theoretically rather clean SM expectation

$R_K^{SM} = 1.0003 \pm 0.0001$ C. Bobeth, G. Hiller, and G. Piranishvili, 0709.4174.

$R_K^{exp} = 0.745^{+0.090}_{-0.074} \pm 0.036$ LHCb 1406.6482

- Explanation:
  - Leptoquarks e.g. G. Hiller, M.Schmaltz, 1408.1627
  - flavour non-universal Z' W. Altmannshofer, et al. 1403.1269

→ Also LFV in B decays? S. L. Glashow et al. 1411.0565.

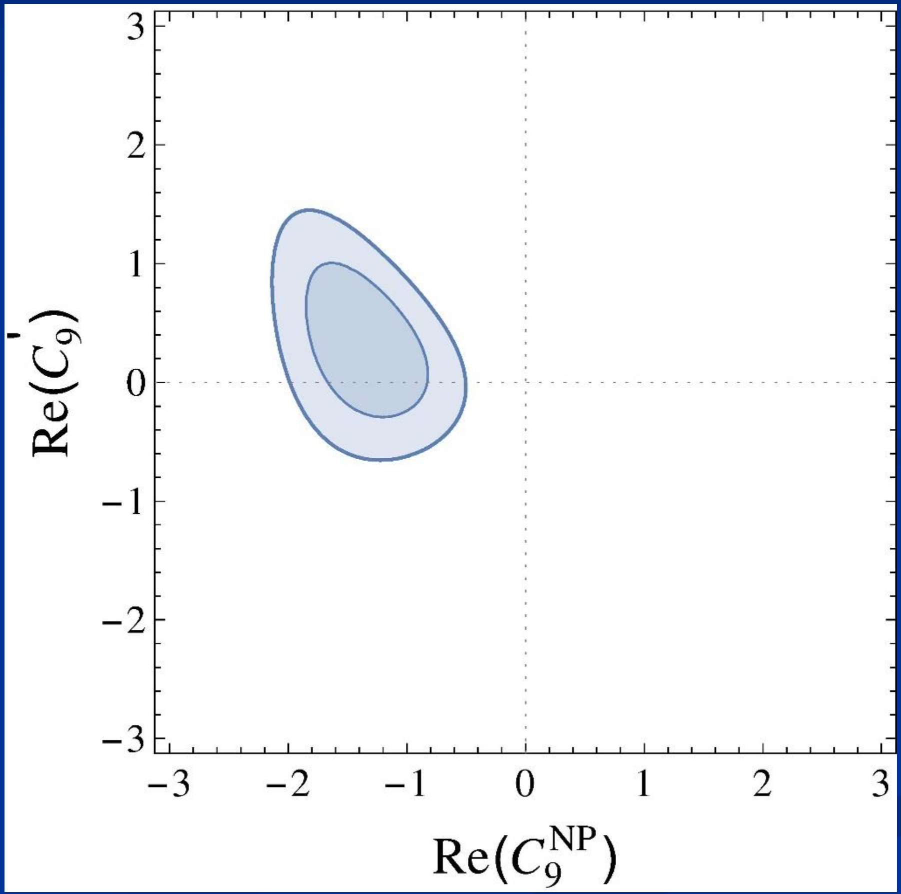
Talk of Lars Hofer

B→K*μμ and R(K)

- Contribution to $C_9^{\mu\mu}$ but not C_9^{ee} gives simultaneously a good fit

W. Altmannshofer and D. M. Straub, 1411.3161.
T. Hurth, F. Mahmoudi, and S. Neshatpour, 1410.4545.
(see talk of Tobias Hurth)

- $C_9^{\mu\mu} = -C_{10}^{\mu\mu}$ possible but less good fit.



arXiv:1411.3161

$h \to \tau\mu$

- 2.4 σ difference from zero

$$\mathrm{Br}[h \to \mu\tau] = \left(0.89^{+0.40}_{-0.37}\right)$$

CMS-PAS-HIG-14-005

- Can be explained in the effective field theory approach by

$$Q^{fi}_{e\phi} = \ell_f \phi e_i \phi^\dagger \phi$$

R. Harnik, J. Kopp, and J. Zupan, 1209.1397.
G. Blankenburg, J. Ellis, and G. Isidori, 1202.5704.
S. Davidson and P. Verdier, 1211.1248.

- No dominant contribution from vector-like fermions A. Falkowski, D. M. Straub, and A. Vicente, 1312.5329

⇒ Extended Higgs sector

A. Dery, et. al. 1408.1371.
M. D. Campos, et. al., 1408.1652.
A. Celis, et. al., 1409.4439.
D. Aristizabal Sierra and A. Vicente, 1409.7690.
C.-J. Lee and J. Tandean, 1410.6803.
J. Heeck, et. al., 1412.3671.

Gauged $L_\mu - L_\tau$

- Vectorial U(1) gauge group: Q(e)=0, Q(μ)=1, Q(τ)=-1
- Anomaly free

X. He, G. C. et al., Phys.Rev. **D43**, 22 (1991).
R. Foot, Mod.Phys.Lett. **A6**, 527 (1991).

- Good zero order approximation to the PMNS matrix:
  - maximal atmospheric and
  - vanishing reactor neutrino mixing angle

$$M_\nu = \begin{pmatrix} X & 0 & 0 \\ 0 & 0 & Y \\ 0 & Y & 0 \end{pmatrix}$$

P. Binetruy, et al., hep-ph/9610481.
N. F. Bell and R. R. Volkas, hep-ph/0008177.
S. Choubey and W. Rodejohann, hep-ph/0411190.
J. Heeck and W. Rodejohann, 1107.5238

⇒ Breaking necessary for a realistic neutrino sector

1HDM
with vector-quarks

The Model

W. Altmannshofer, S. Gori, M. Pospelov, and I. Yavin, 1403.1269.

- Gauged $L_\mu - L_\tau$: Z' boson with

$$-ig'\,\bar{\ell}_f \gamma^\mu Z'_\mu \ell_i \begin{pmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & -1 \end{pmatrix}_{fi}$$

- Vector-like quarks charged under $L_\mu - L_\tau$

$$m_Q \bar{Q}_L \tilde{Q}_R + m_D \bar{\tilde{D}}_L D_R + m_U \bar{\tilde{U}}_L U_R + \mathrm{h.c.}$$

- Effective Z' quark couplings

P. Langacker, 0801.1345., A. J. Buras, F. De Fazio, and J. Girrbach, 1211.1896.

$$ig'\gamma^\mu d_f \left(\Gamma^L_{fi} P_L + \Gamma^R_{fi} P_R\right) d_i Z'_\mu$$

$$\Gamma^{dR}_{ij} \simeq -\frac{v_\Phi^2}{2m_D^2}(Y_i^D Y_j^{D*}), \quad \Gamma^{dL}_{ij} \simeq \frac{v_\Phi^2}{2m_Q^2}(Y_i^Q Y_j^{Q*})$$

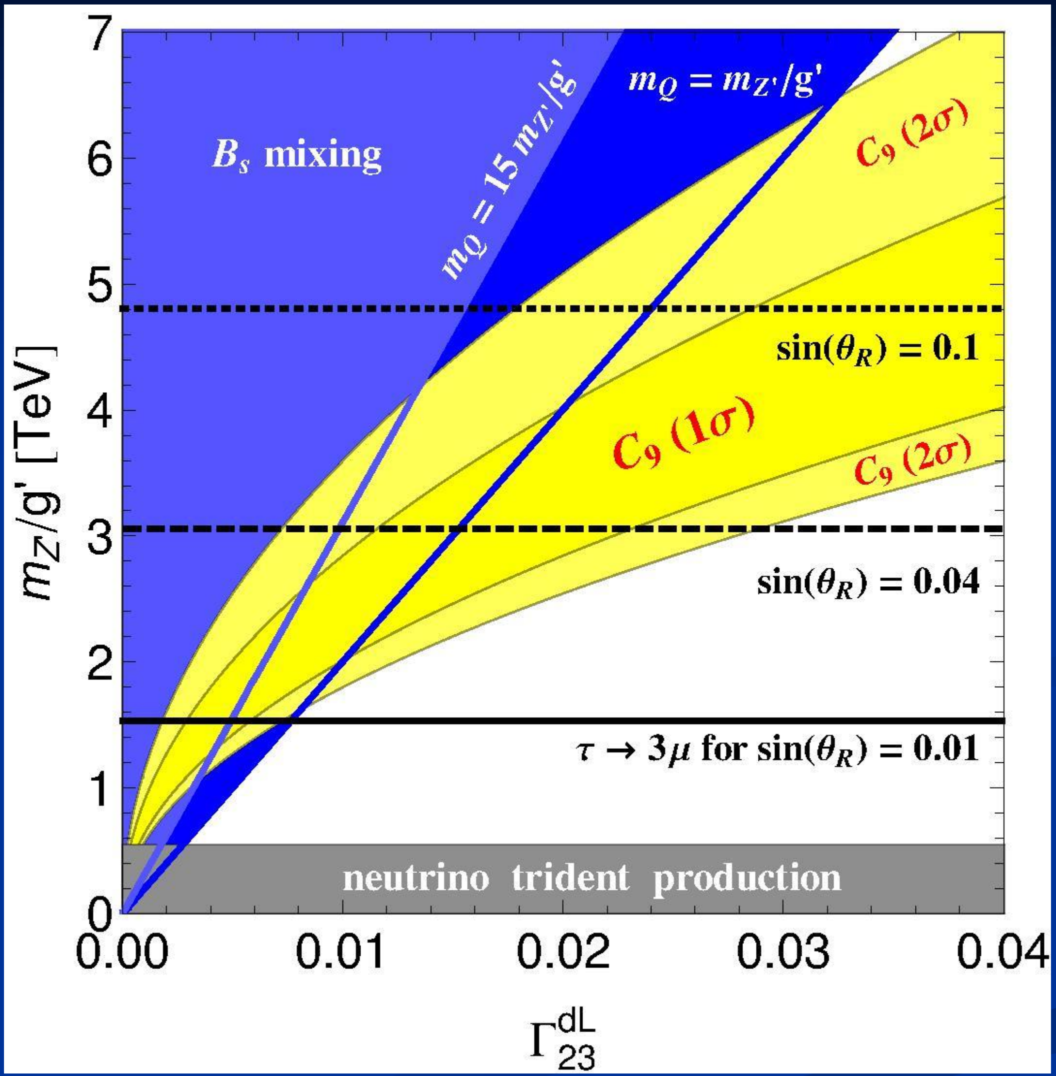
$$m_D^2 \to \infty$$

B→K*μμ, R(K)

$$C_9^{\mu\mu} \sim \Gamma_{23}^{dL} \frac{g'^2}{m_{Z'}^2}$$

B_s mixing

$$\frac{\Delta M_{12}}{M_{12}^{SM}} \sim \Gamma_{23}^{dL} \frac{g'^2}{m_{Z'}^2}$$



allowed regions

2HDM with vector-quarks

Explaining $B \to K^* \mu\mu$, $B \to K\mu\mu / B \to Kee$ and $h \to \tau\mu$ in a two-Higgs-doublet model with gauged L_μ-L_τ
arXiv:1501.00993

2nd Doublet breaks $L_\mu - L_\tau$

J. Heeck, M. Holthausen, W. Rodejohann and Y. Shimizu, 1412.3671

- Two Higgs doublets

$$Q_{L_\mu - L_\tau}(\Psi_2) = 0 \qquad Q_{L_\mu - L_\tau}(\Psi_1) = 2$$

- Yukawa couplings

$$\mathcal{L}_Y \supset -\bar{\ell}_f Y_i^\ell \delta_{fi} \Psi_2 e_i - \xi_{\tau\mu} \bar{\ell}_3 \Psi_1 e_2 - \bar{Q}_f Y_{fi}^u \tilde{\Psi}_2 u_i - \bar{Q}_f Y_{fi}^d \Psi_2 d_i + \text{h.c.}.$$

- Flavour changing SM-like Higgs coupling

$$\Gamma_{\tau\mu}^h \bar{\tau} P_R \mu h^0 \approx \frac{m_\tau}{v} \frac{\cos(\alpha - \beta)}{\cos(\beta)\sin(\beta)} \theta_R \bar{\tau} P_R \mu h^0$$

$$\sin\theta_R \simeq \frac{v}{\sqrt{2} m_\tau} \xi_{\tau\mu} \cos\beta$$

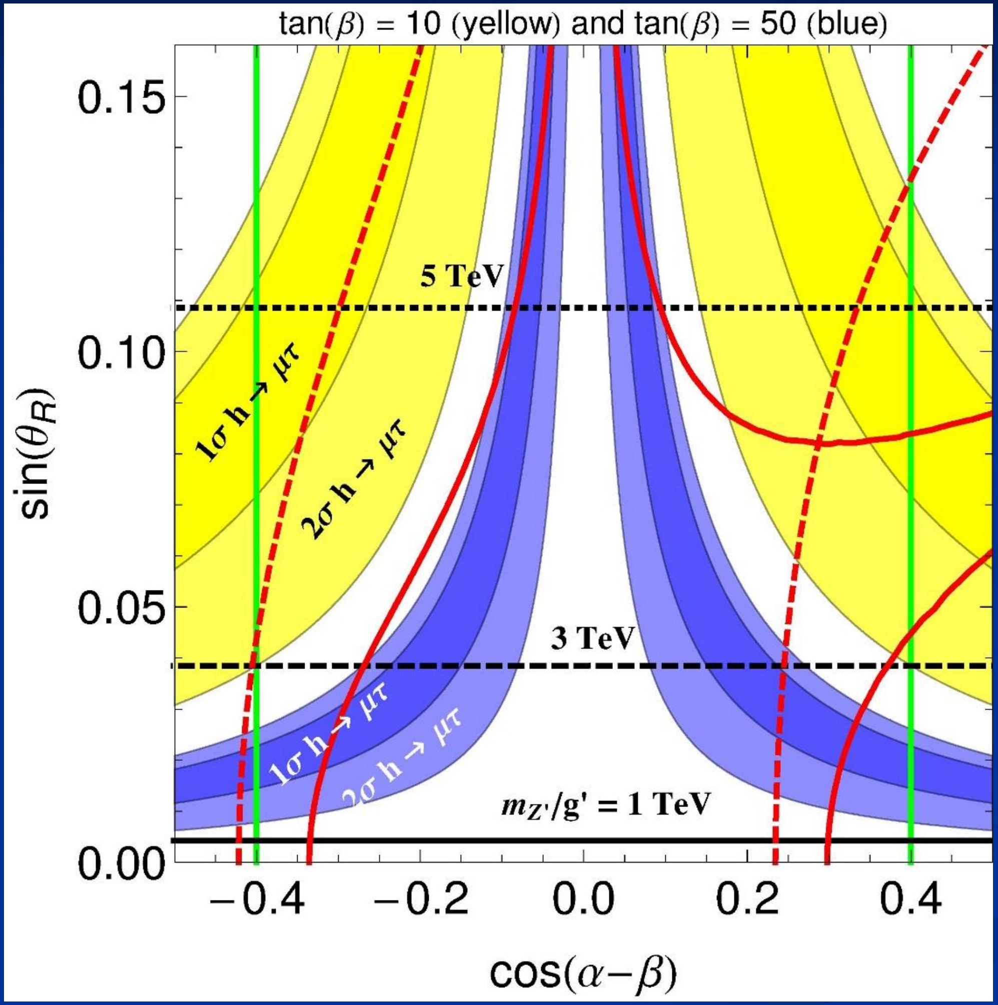
$$\sin\theta_L \simeq 0$$

- Lepton flavour violating Z' couplings

$$g' Z'(\bar{\mu}, \bar{\tau}) \begin{pmatrix} \cos 2\theta_R & \sin 2\theta_R \\ \sin 2\theta_R & -\cos 2\theta_R \end{pmatrix} \gamma^\nu P_R \begin{pmatrix} \mu \\ \tau \end{pmatrix}$$

$h \to \mu\tau$ and $\tau \to \mu\mu\mu$

$h \to \gamma\gamma$ etc.



$h \to \tau\tau$

$h \to \mu\tau \ (\tan\beta = 50)$

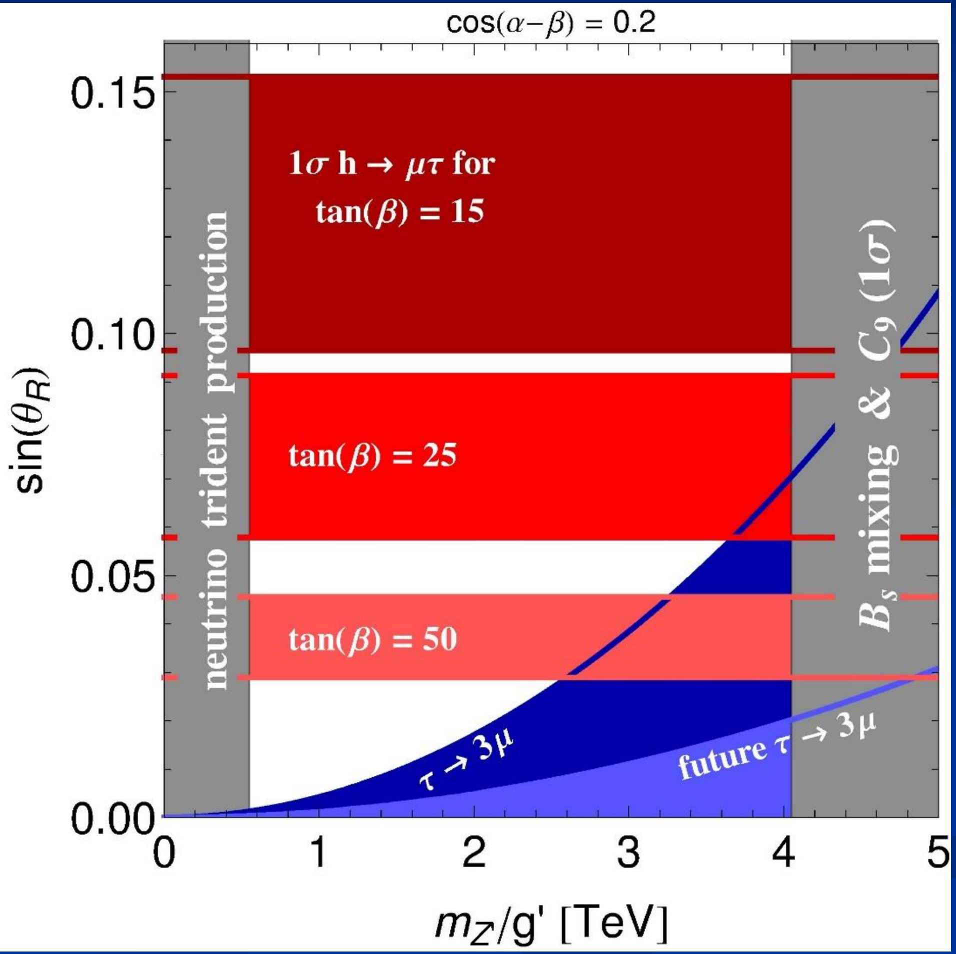
$h \to \mu\tau \ (\tan\beta = 10)$

$\tau \rightarrow \mu\mu\mu$ **and** $h \rightarrow \mu\tau$

excluded

allowed by $h \rightarrow \tau\mu$

allowed by $\tau \rightarrow \mu\mu\mu$



Horizontal charges

Andreas Crivellin, Giancarlo D'Ambrosio and Julian Heeck

Adressing the LHC flavour anomalies with horizontal gauge symmetires (in preperation)

Charge assignmet

- Avoid vector-like quarks by assigning charges to baryons as well

⇨ same mechanism in the quark and lepton sector

- Use $L_\mu - L_\tau$ in the lepton sector

⇨ good symmetry for the PMNS matrix
effect in $C_9^{\mu\mu}$ but not C_9^{ee}

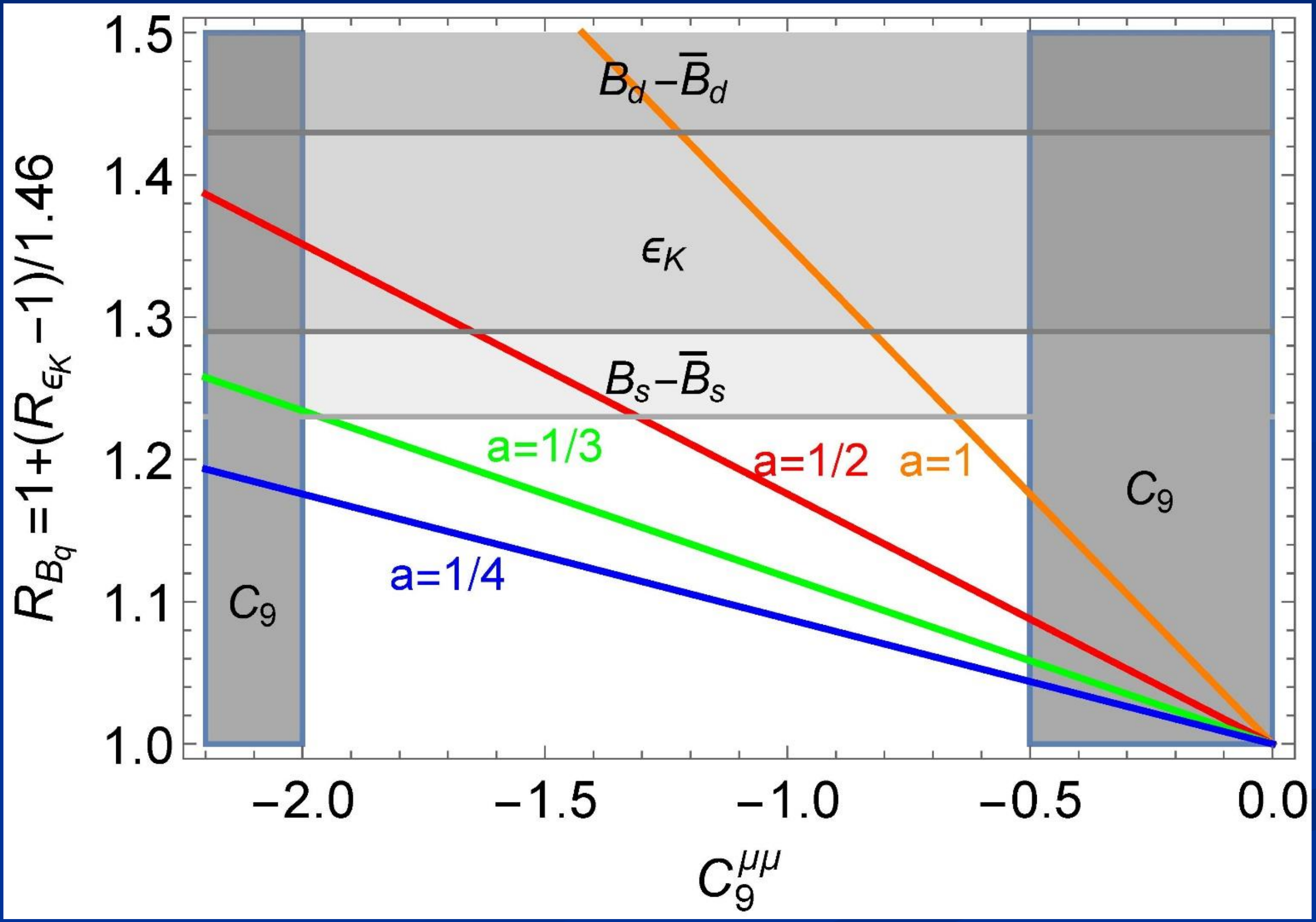
- First two quark generations must have the same charges because the large Cabibbo angle would lead to huge effect in Kaon mixing
- Anomaly free

⇨ $Q(B) = (-a, \quad -a, \quad 2a)$

ΔF=2: Z' contribution

$$R_{B_q} = \frac{\Delta m_{B_q}}{\Delta m_{B_q}^{SM}}$$

$$R_{\epsilon_K} = \frac{\epsilon_K}{\epsilon_K^{SM}}$$



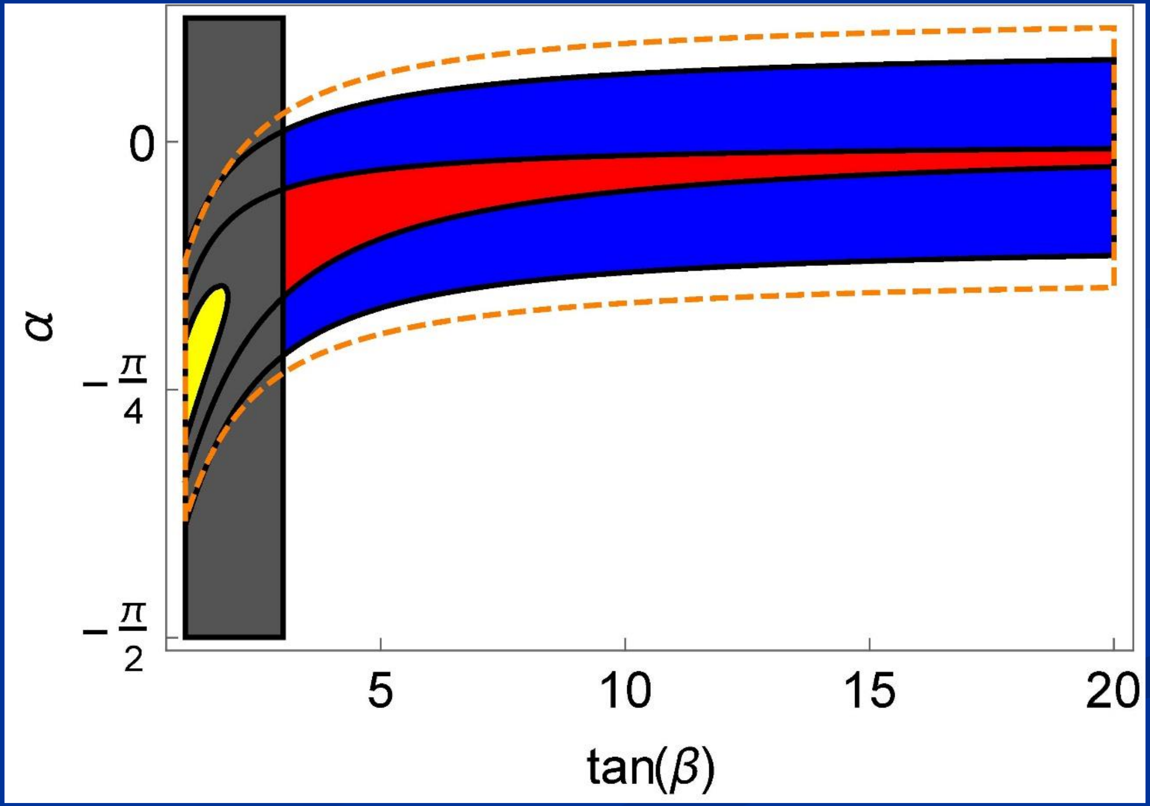
ΔF=2: Higgs contributions

$$m_H = 300\ \text{GeV}, \quad C_9^{\mu\mu} = -1.3$$

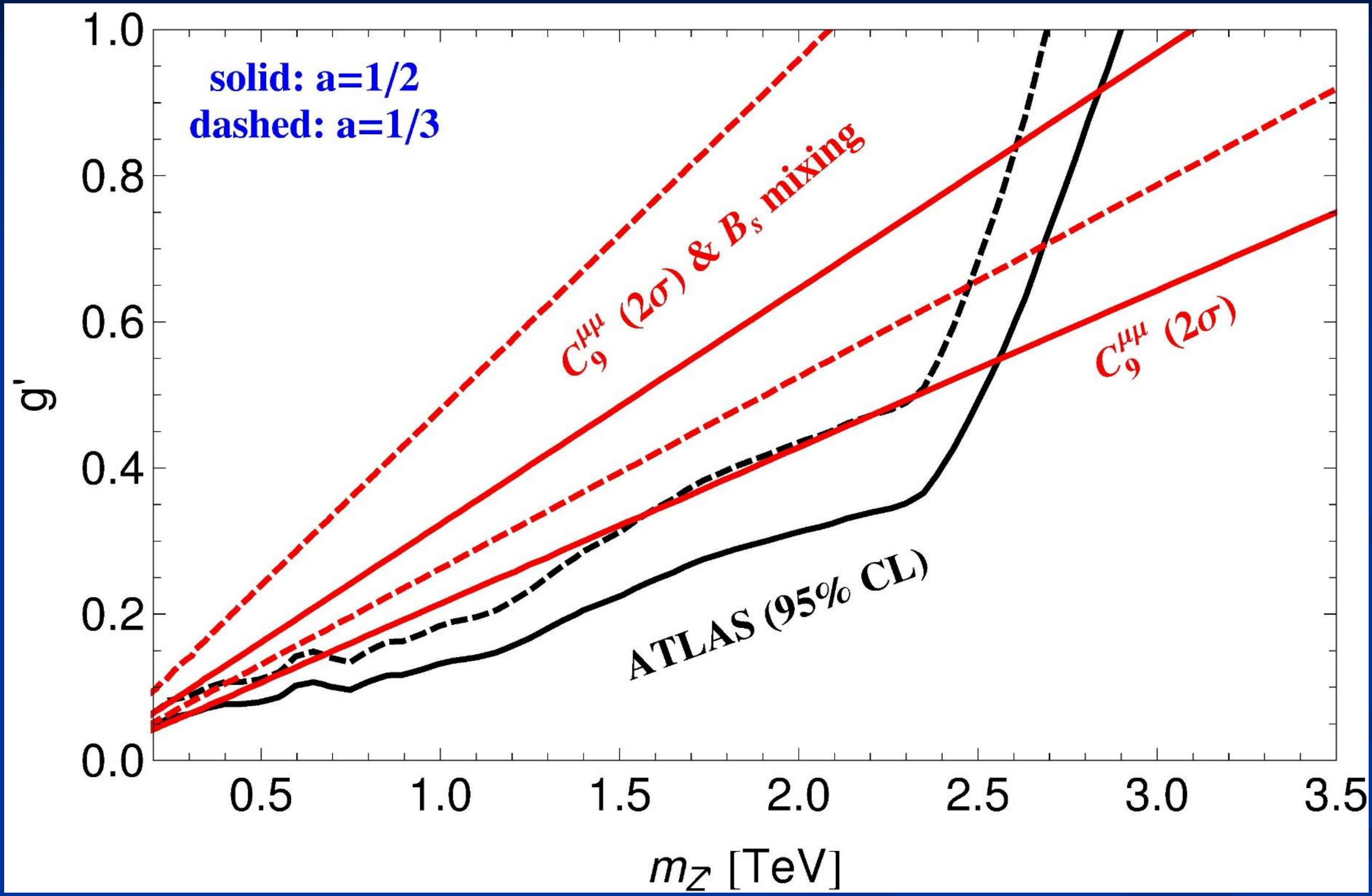
$m_A = 250\ \text{GeV}$

$m_A = 300\ \text{GeV}$

$m_A = 350\ \text{GeV}$



LHC limits



ATLAS

$C_9^{\mu\mu}$ & $B_s - \overline{B}_s$

3HDM

- Same effect in

$$\tau \rightarrow \mu\mu\mu$$

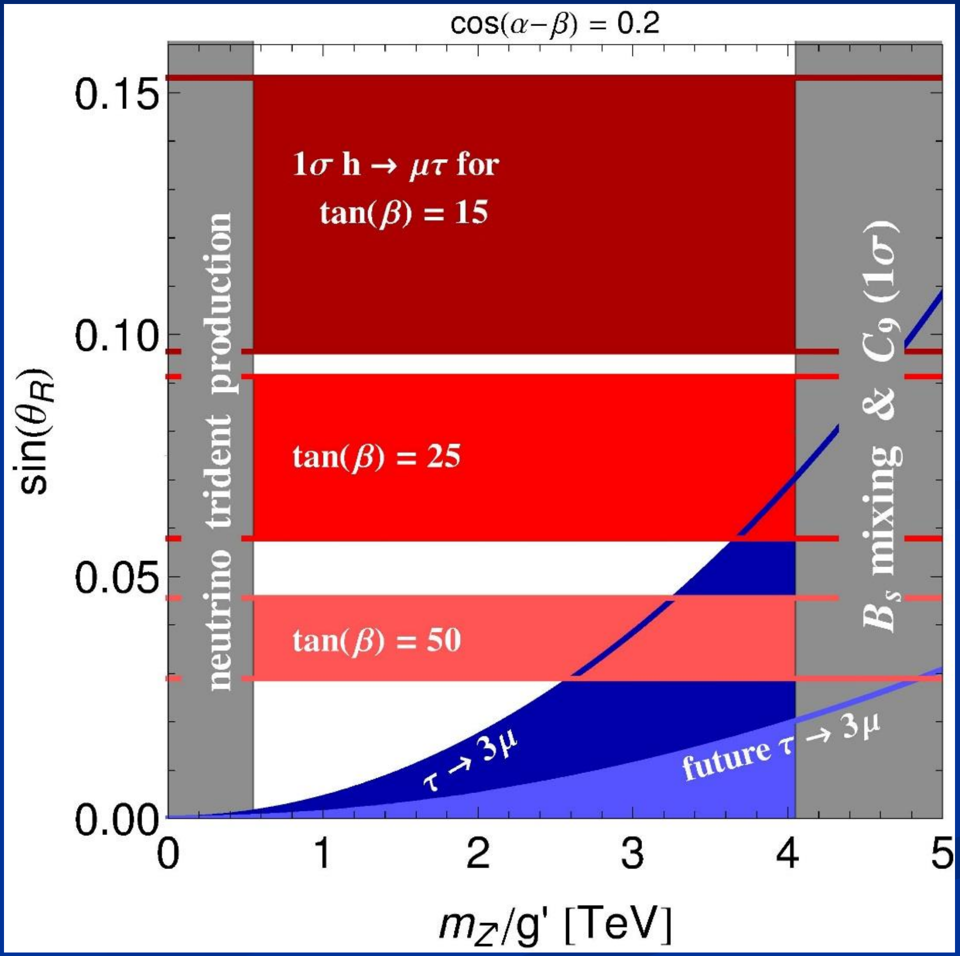
$$h \rightarrow \mu\tau$$

provided that the mixing among the doublets is small

excluded

allowed by $h \rightarrow \tau\mu$

allowed by $\tau \rightarrow \mu\mu\mu$



Conclusions

- The LHC found three anomalies in the flavour sector
  - $h \to \tau\mu$
  - $B \to K^{*}\mu^{+}\mu^{-}$
  - $B \to K\mu^{+}\mu^{-} / B \to Ke^{+}e^{-}$
- All three anomalies can be explained in a model with gauged $L_\mu - L_\tau$
  - 2HDM with vector-quarks
  - 3HDM with gauged flavour dependent B-L charges