University of Zurich[UZH]

Model building for non-leptonic anomalies

(and semileptonic ones)

Javier M. Lizana
Zurich University

Ongoing project in collaboration with J. Matias and B. A. Stefanek

Beyond Flavor Anomalies - Barcelona - April 2023

[Algueró, Crivellin, Descotes-Genon, Matias, Novoa-Brunet, 2011.07867]
[Biswas, Descotes-Genon, Matias, Tetlalmatzi-Xolocotzi 2301.10542]

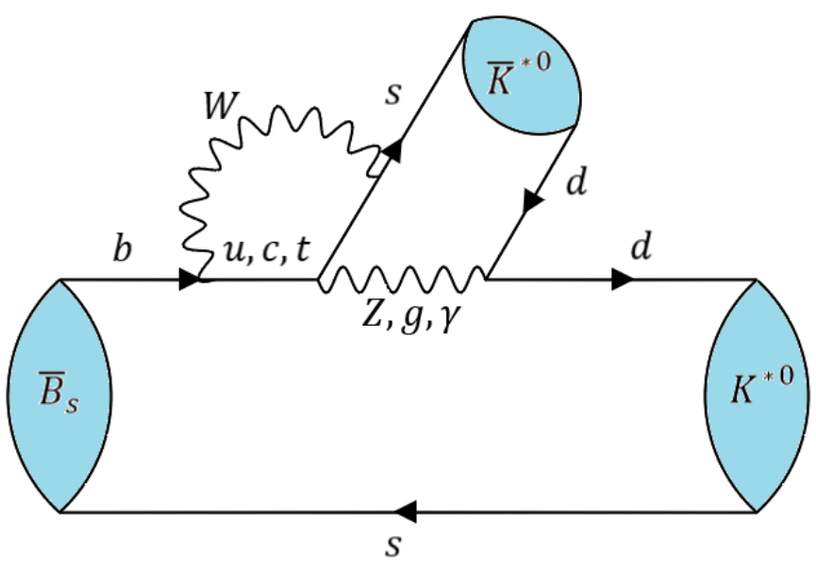
$L_{K^{(*)}\bar{K}^{(*)}}$ observables

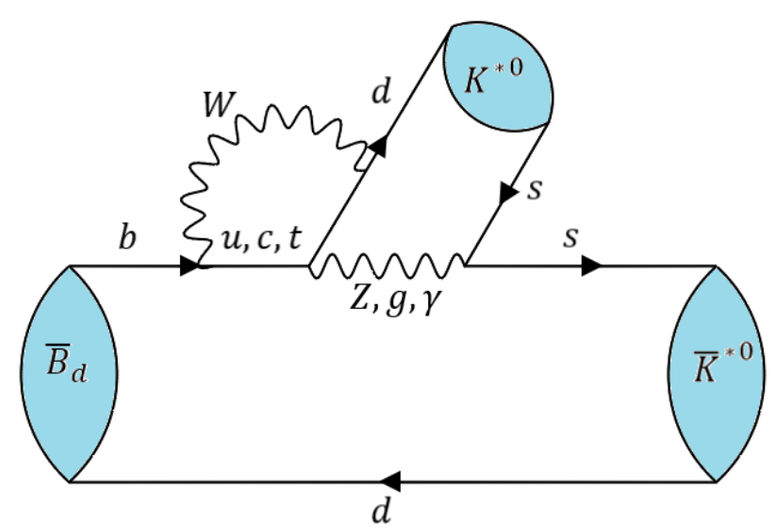
- Something is going on with the non-leptonic B decays.
- We focus on the $L_{K^{(*)}\bar{K}^{(*)}}$ observables:

$$L_{K^*\bar{K}^*} = \rho(m_{K^{*0}}, m_{K^{*0}}) \frac{\mathscr{B}(\bar{B}_s \to K^{*0}\bar{K}^{*0})}{\mathscr{B}(\bar{B}_d \to K^{*0}\bar{K}^{*0})} \frac{f_L^{B_s}}{f_L^{B_d}} = \frac{|A_0^s|^2 + |\bar{A}_0^s|^2}{|A_0^d|^2 + |\bar{A}_0^d|^2}$$

$$L_{K\bar{K}} = \rho(m_{K^0}, m_{K^0}) \frac{\mathscr{B}(\bar{B}_s \to K^0\bar{K}^0)}{\mathscr{B}(\bar{B}_d \to K^0\bar{K}^0)} = \frac{|A^s|^2 + |\bar{A}^s|^2}{|A^d|^2 + |\bar{A}^d|^2}$$

Longitudinal component of $B \to K^{(*)}\bar{K}^{(*)}$





[Algueró, Crivellin, Descotes-Genon, Matias, Novoa-Brunet, 2011.07867]
[Biswas, Descotes-Genon, Matias, Tetlalmatzi-Xolocotzi 2301.10542]

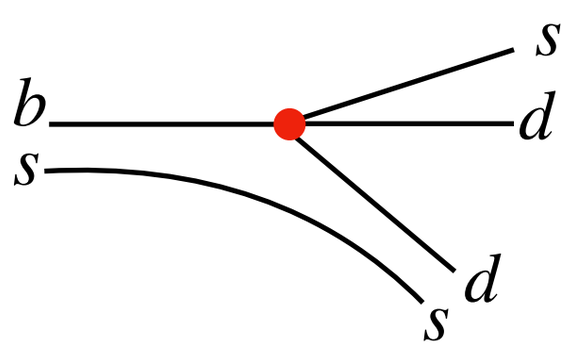
NP in $L_{K^{(*)}\bar{K}^{(*)}}$

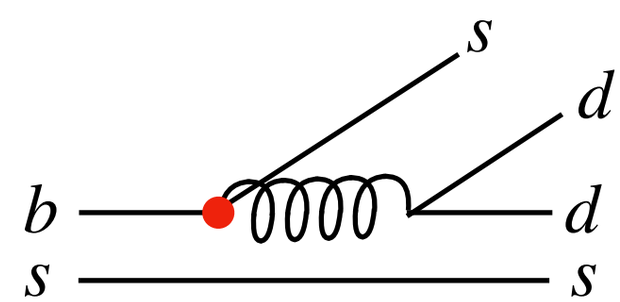
$$L^{\rm SM}_{K^*\bar{K}^*} = 19.53^{+9.14}_{-6.64} \qquad L^{\rm exp}_{K^*\bar{K}^*} = 4.43 \pm 0.92 \quad \rightarrow \quad 2.6\sigma$$

$$L^{\rm SM}_{K\bar{K}} = 26.00^{+3.88}_{-3.59} \qquad L^{\rm exp}_{K\bar{K}} = 14.58 \pm 3.37 \quad \rightarrow \quad 2.4\sigma$$

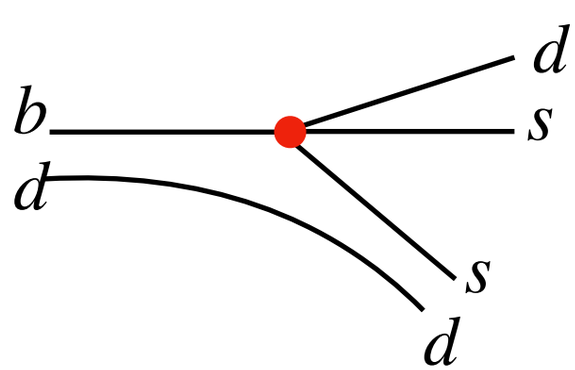
4-quark op. | Chromod. dipole

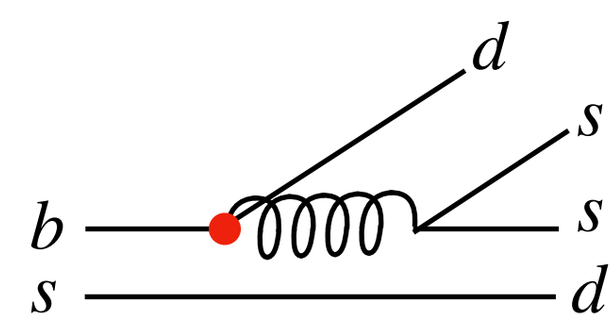
$\bar{B}_s \to K^0\bar{K}^0$
$(b \to s)$





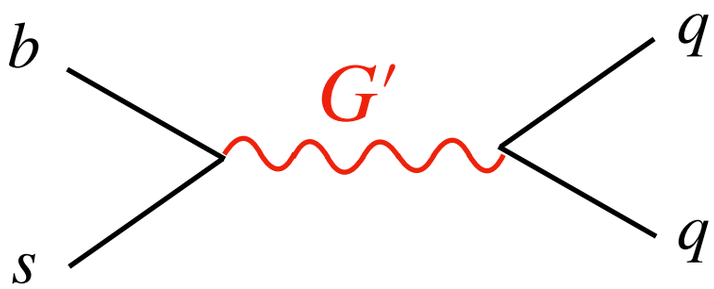
$\bar{B}_d \to K^0\bar{K}^0$
$(b \to d)$





C_{4s} : Coloron

$$G' \sim (\mathbf{8}, \mathbf{1})_{\mathbf{0}}$$



$$\mathscr{L} \supset \frac{2V_{tb}V_{ts}^*}{v_{\rm EW}^2} C_{4s} \left(\bar{s}_L^\alpha \gamma_\mu b_L^\beta\right) \left(\bar{q}^\beta \gamma_\mu q^\alpha\right)$$

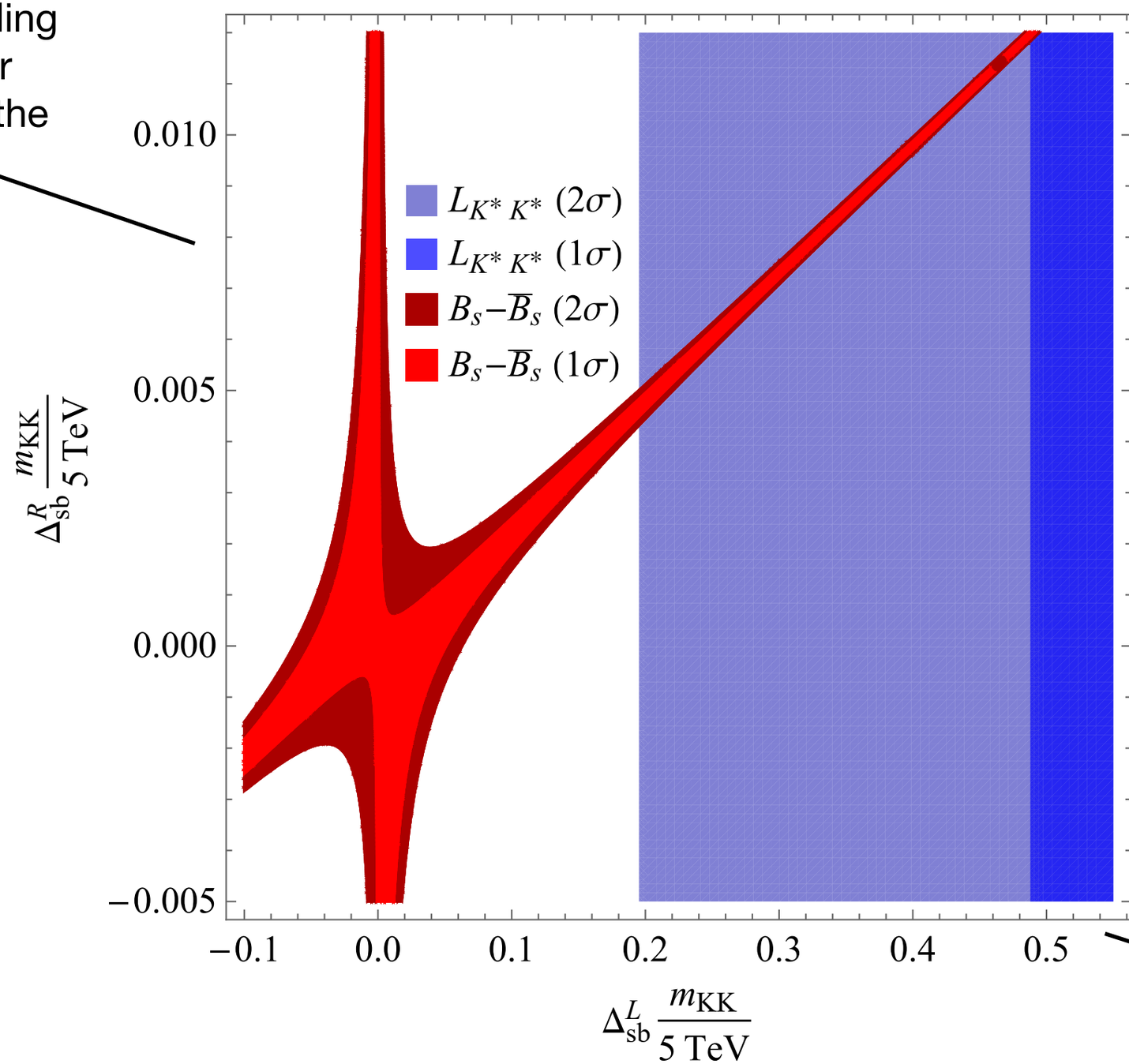
$$\mathscr{L} \supset \Delta_{sb}^L (\bar{s}_L \gamma^\mu b_L)\, G'_\mu + \Delta_{sb}^R (\bar{s}_R \gamma^\mu b_R)\, G'_\mu + \sum_i \Delta_{qq} (\bar{q}_i \gamma^\mu q_i)\, G'_\mu$$

- $L_{K^{(*)}\bar{K}^{(*)}}$ observables: $\dfrac{\Delta_{sb}\Delta_{qq}}{m_{G'}^2} \sim \dfrac{1}{(5\,\text{TeV})^2}$
- From di-jet searches: $\dfrac{\Delta_{qq}^2}{m_{G'}^2} \lesssim \dfrac{1}{(5\,\text{TeV})^2}$
- B_s mixing: $\dfrac{\Delta_{sb}^2}{m_{G'}^2} \lesssim \dfrac{1}{(100\,\text{TeV})^2}$

✗

Except…

Suppressed RH coupling to generate a scalar operator that cancel the vector one



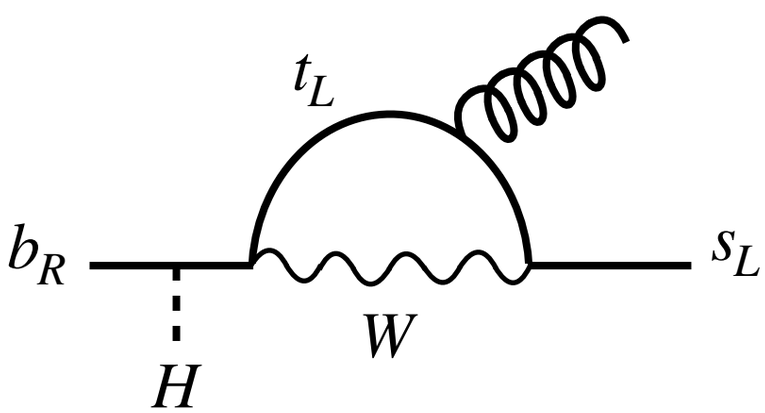
Large bs couplings (Difficult to produce in a UV model)

[Algueró, Crivellin, Descotes-Genon, Matias, Novoa-Brunet, 2011.07867]

A different direction: C_{8gs}

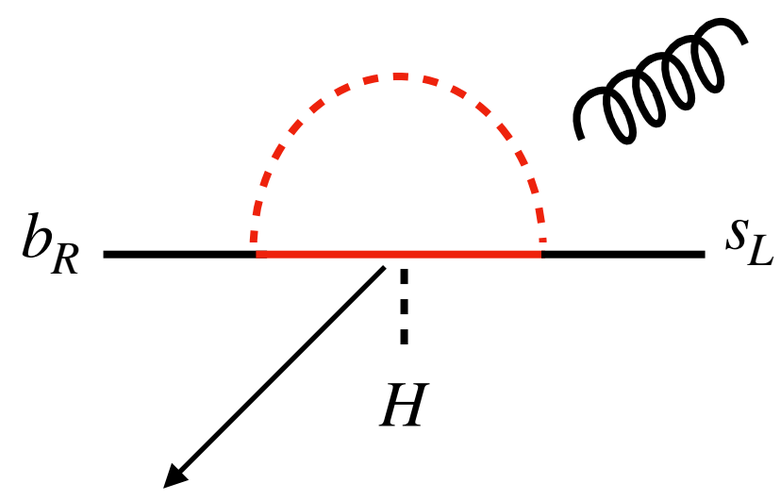
$$-\mathscr{L} \supset \frac{2m_b V_{tb} V_{ts}^*}{8\pi^2 v_{\rm EW}^2} C_{8gs} \left(\bar{s}_L \sigma_{\mu\nu} G^{\mu\nu} b_R \right)$$

In the SM:



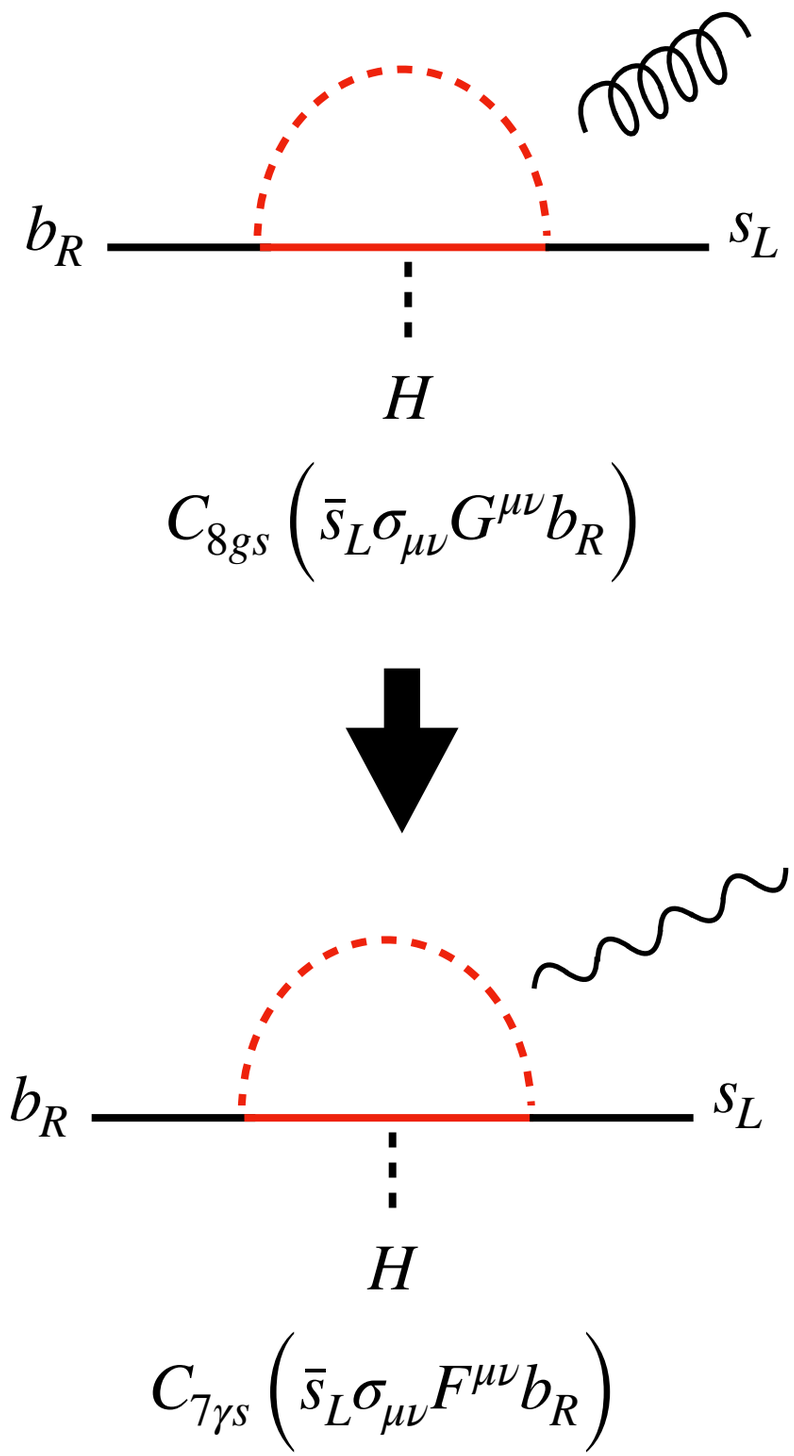
TeV NP:

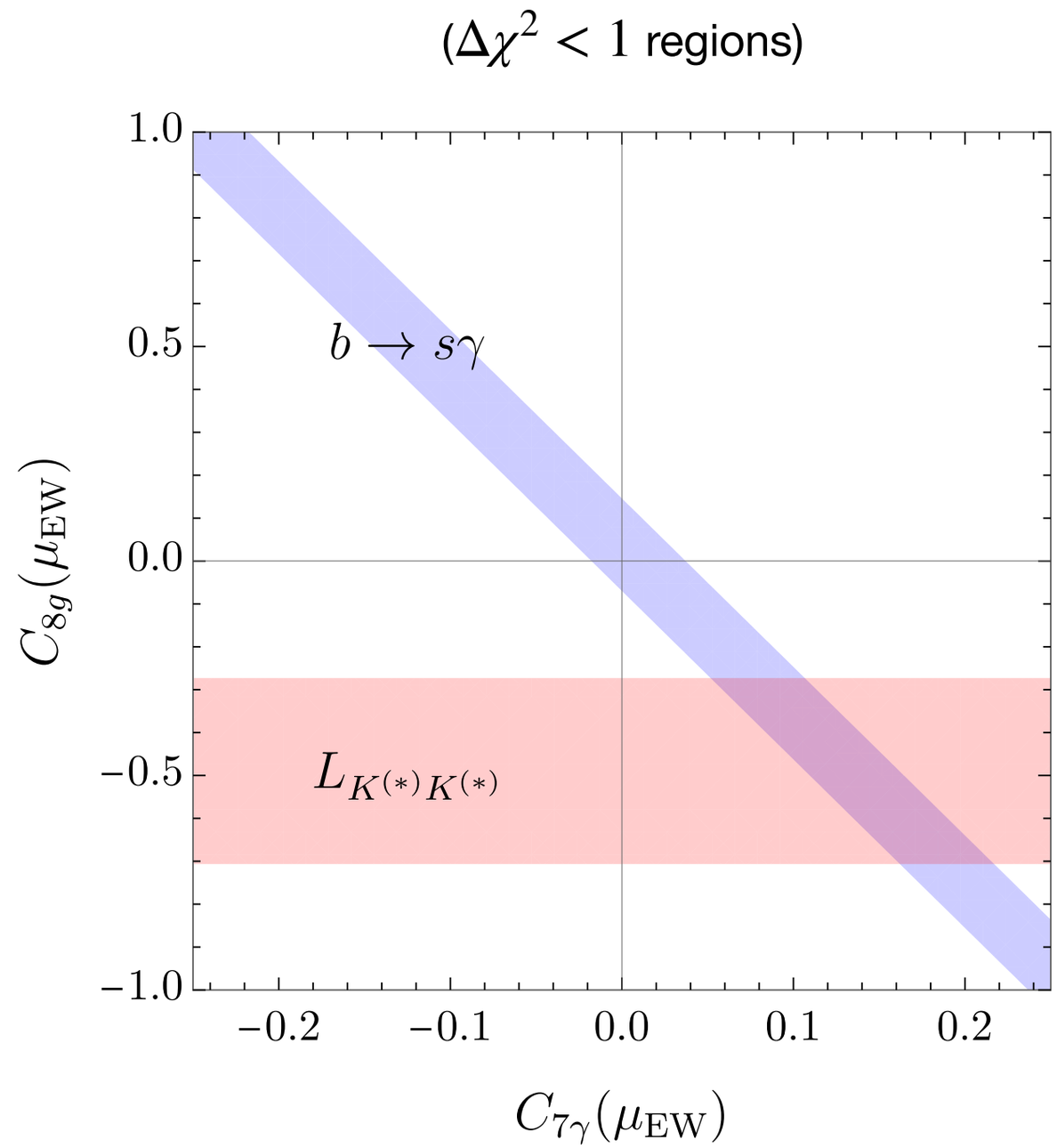
(We need $C_{8gs}^{\rm NP} \sim - C_{8gs}^{\rm SM}$)



Non-chirally suppressed

Watch out! The EM dipole!

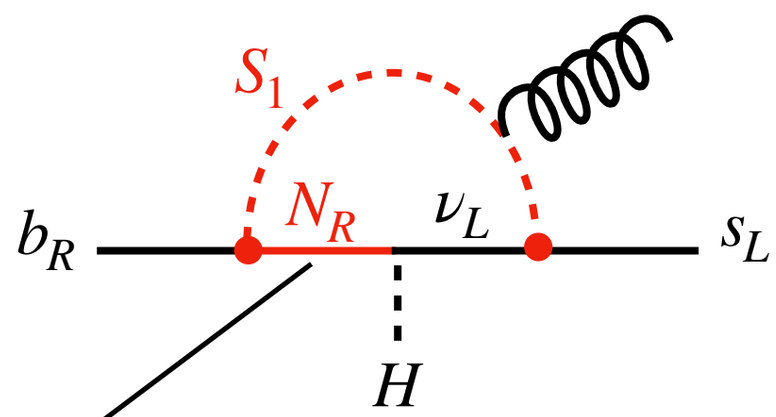




[Gherardi, Marzocca, Venturini ,2008.09548]

Scalar leptoquark S_1 + inverse seesaw

- A scalar LQ $S_1 \sim (\mathbf{3},\mathbf{1})_{-1/3}$ can generate the dipole and address $R_{D^{(*)}}$.

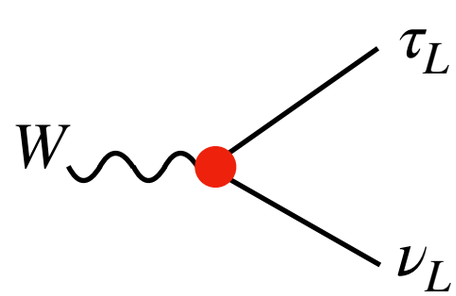


We need a TeV N_R with a *large* Yukawa → Inverse seesaw

$$\mathscr{L} \supset -y_\nu \bar{\ell}_L^3 \tilde{H} N_R - M_R \bar{N}_L N_R - \frac{1}{2}\mu \bar{N}_L N_L^c \qquad (\mu \ll M_R)$$

$$\nu_L^3 \to \cos(\theta_\tau)\,\nu_L^3 + \sin(\theta_\tau)\,N_L$$

$\sin(\theta_\nu) = y_\nu v_{\rm EW}/M_R$ →

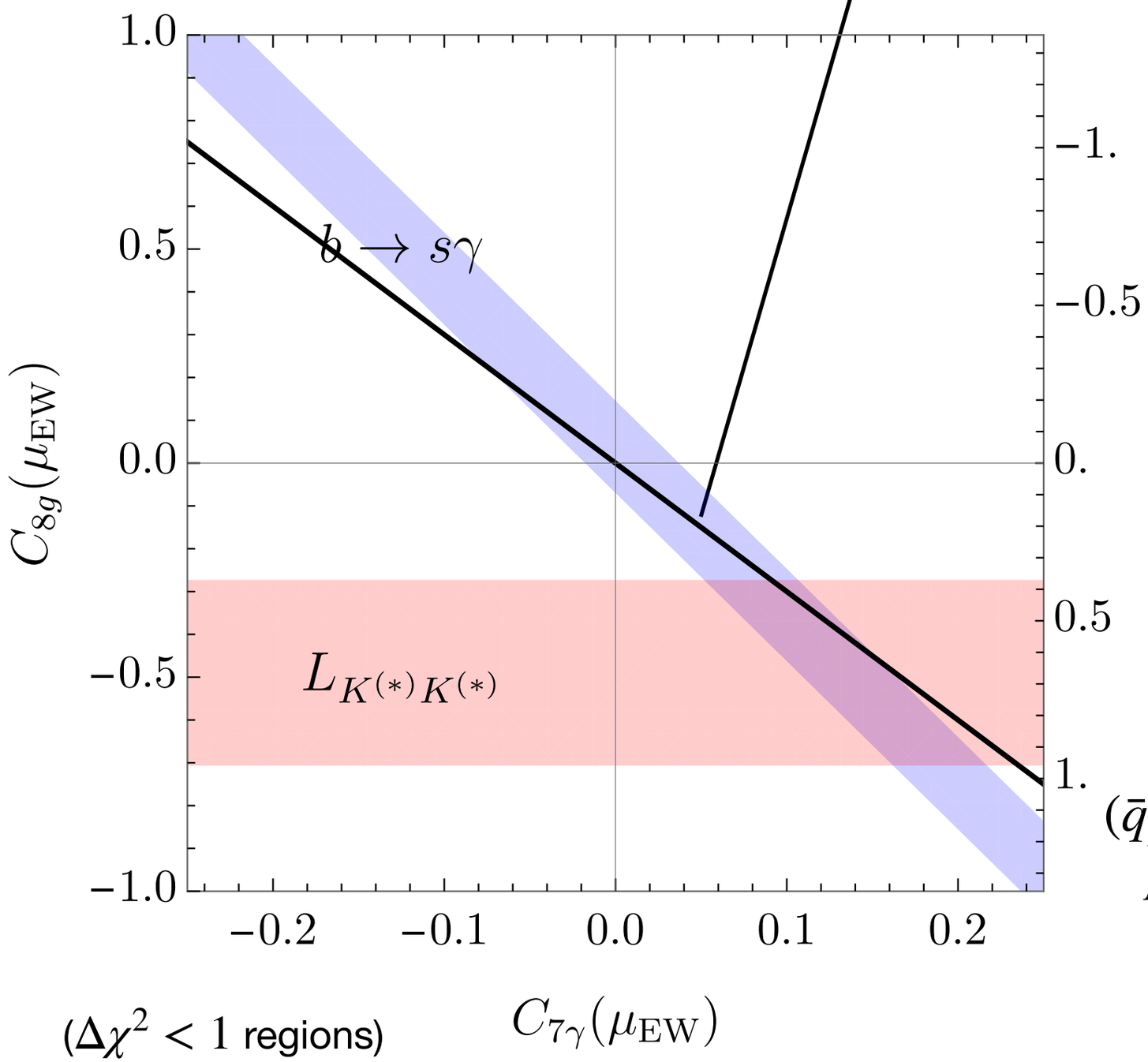


→ $\theta_\nu \lesssim 0.05$

(EWPD + τ decays)

The EM dipole, again

$S_1 \sim (\mathbf{3}, \mathbf{1})_{-1/3}$



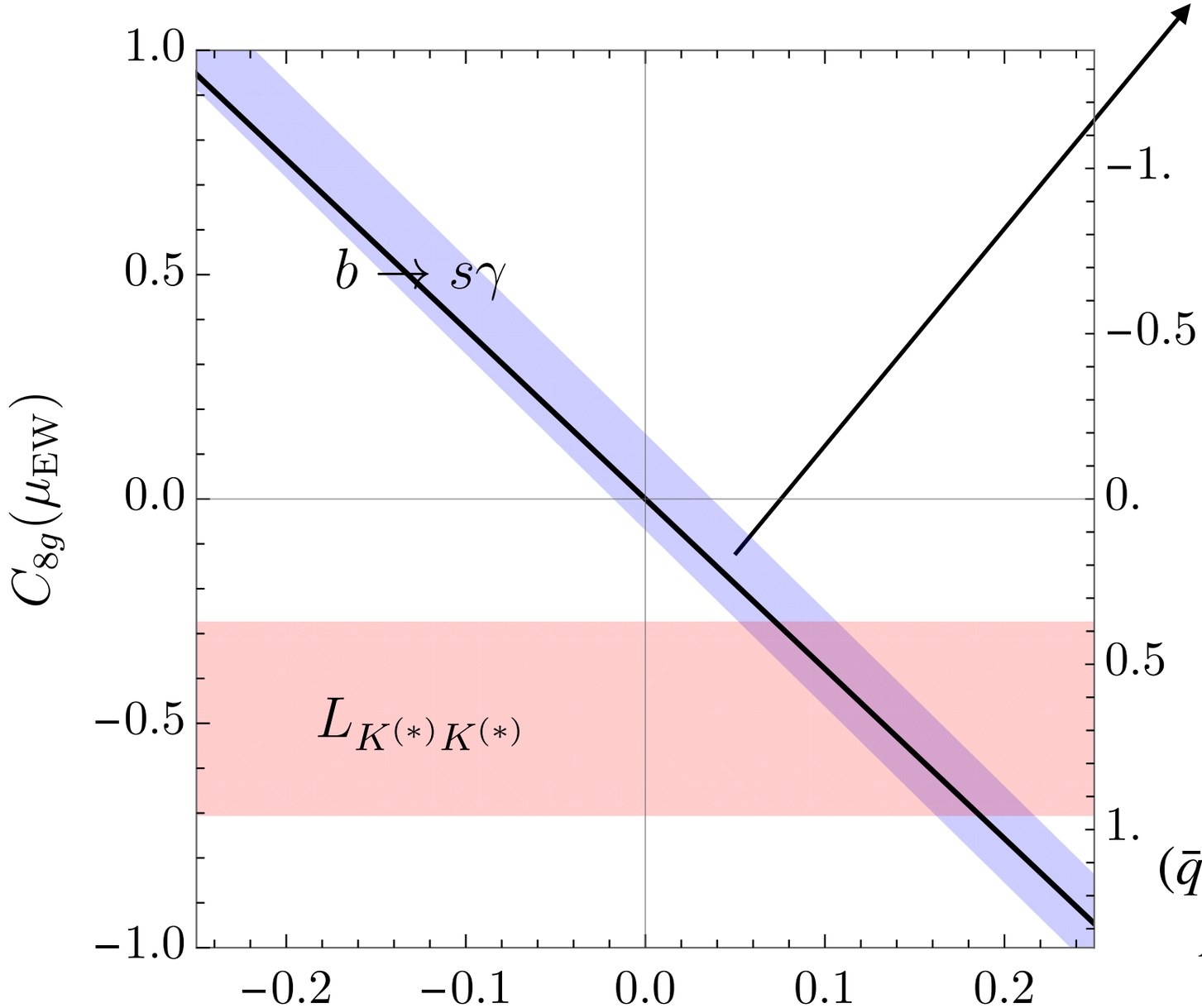
$(\bar{q}_L^2 \epsilon \ell_3^c) S_1$ coupling assuming $M_{S_1} = 2\,\text{TeV}$, $\theta_\tau = 0.05$, and $\lambda_R^b = -2$, $(\bar{b}_R S_1 N_R)$.

($\Delta\chi^2 < 1$ regions)

The EM dipole, again

$S_1 \sim (\mathbf{3}, \mathbf{1})_{-1/3}$

Including RG running from $2\,\mathrm{TeV}$ to μ_{EW}

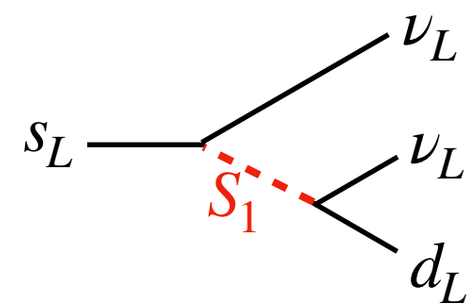


$(\bar{q}_L^2 \epsilon \ell_3^c) S_1$ coupling assuming $M_{S_1} = 2\,\mathrm{TeV}$, $\theta_\tau = 0.05$, and $\lambda_R^b = -2$, $(\bar{b}_R S_1 N_R)$.

($\Delta\chi^2 < 1$ regions)

But…

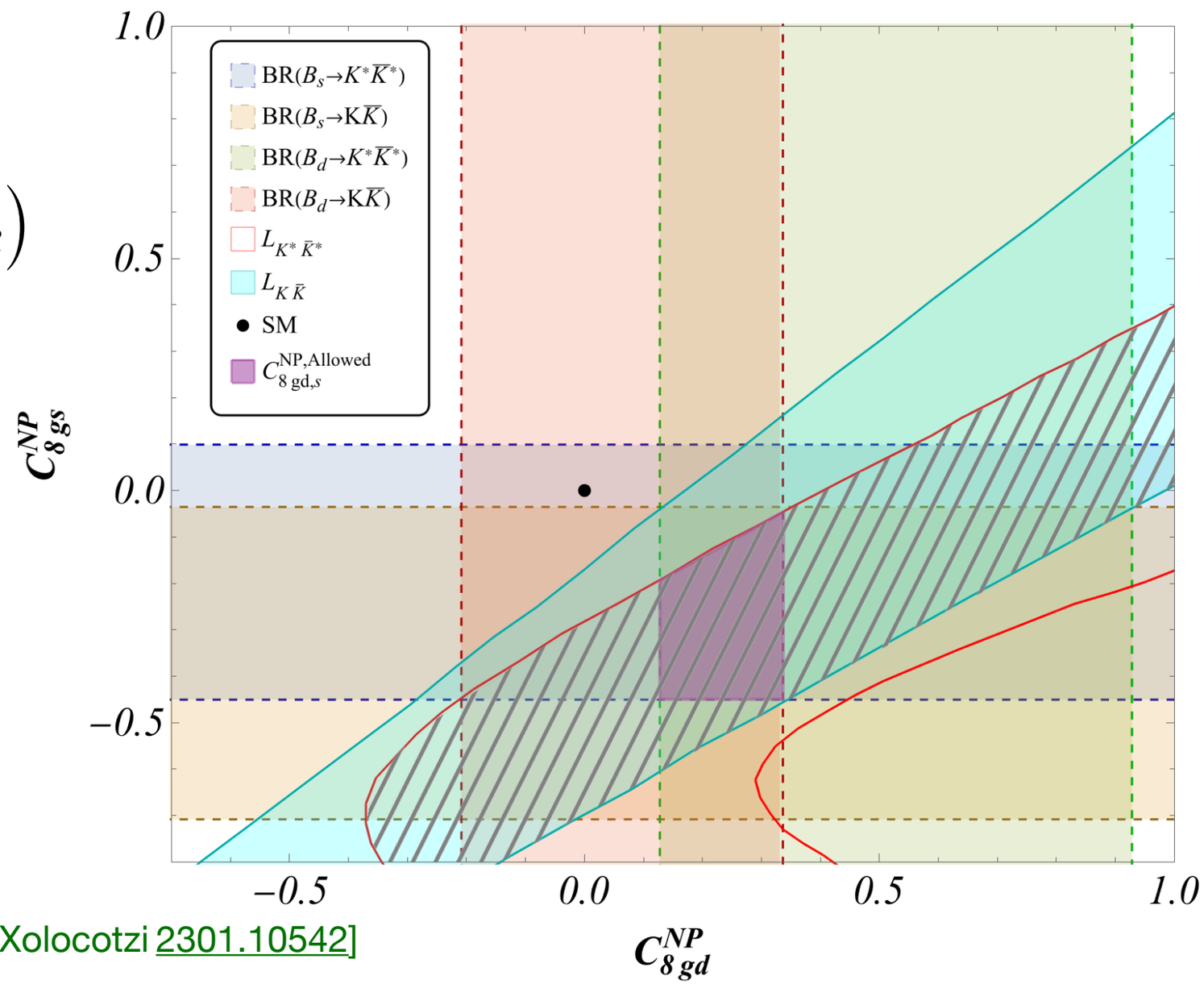
- Couplings of S_1 to d must be very suppressed to avoid $K^+ \to \pi^+ \nu\nu$:



- No $b \to d$

$$-\mathscr{L} \supset \frac{2 m_b V_{tb} V_{td}^*}{8\pi^2 v_{\rm EW}^2} C_{8gd} \left(\bar{d}_L \sigma_{\mu\nu} G^{\mu\nu} b_R \right)$$

- But branching ratios:



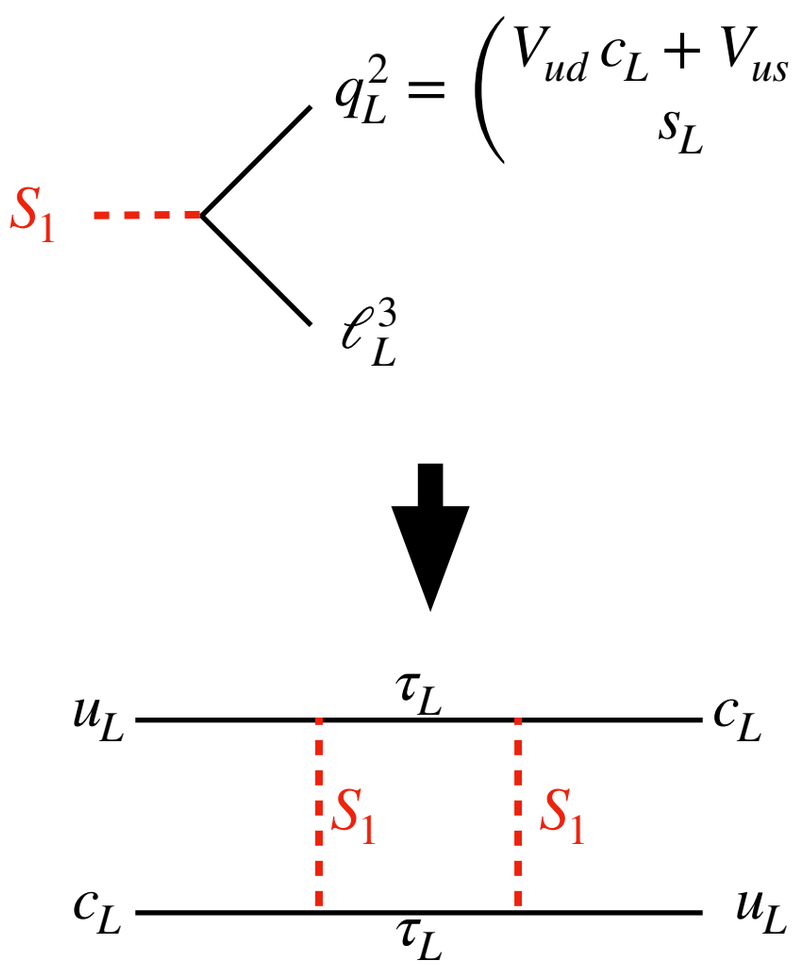
[Biswas, Descotes-Genon, Matias, Tetlalmatzi-Xolocotzi 2301.10542]

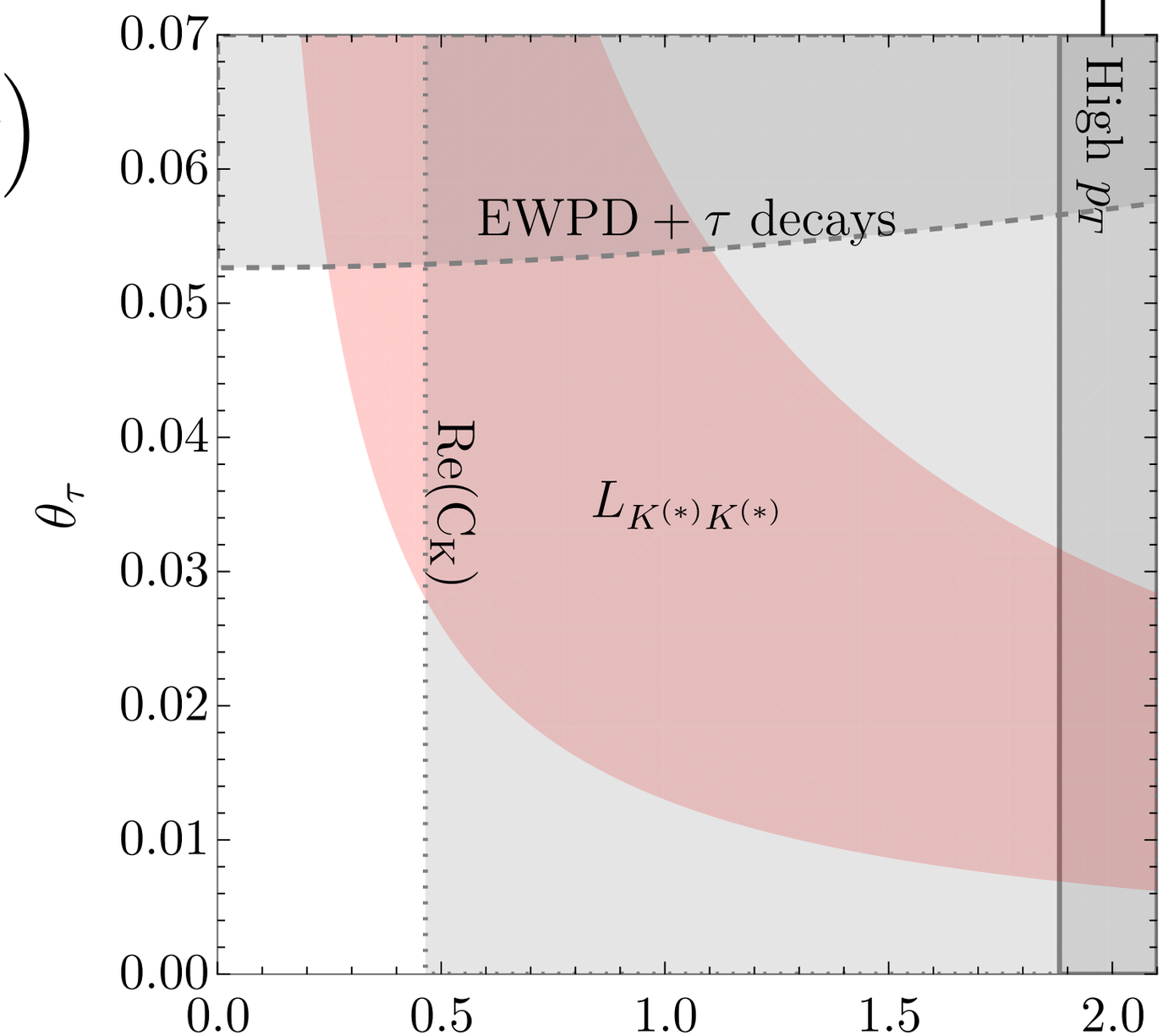
But…

HighPT [Allwicher, Faroughy, Jaffredo, Sumensari, Wilsch, 2207.10756] (see Felix's talk)

$pp \to \tau\tau$ & $pp \to \tau \not{E}_T$

- Large breaking of flavor $U(2)_q$ symmetry. Bounds from $D - \bar{D}$ mixing:





$(M_{S_1} = 2\,\text{TeV},\ \lambda_R^b = -2)$

$U(2)$ to the rescue!

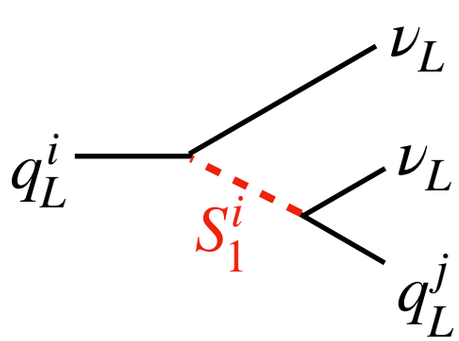
- Idea to improve the situation: promote S_1 to a doublet of $U(2)_q$:

$$S_1 \longrightarrow (S_1^d, S_1^s)$$

$$\lambda_L^s\,(\bar{q}_L^2 \epsilon \ell_3^c) S_1 \longrightarrow \lambda_L\,(\bar{q}_L^i \epsilon \ell_3^c) S_1^i$$

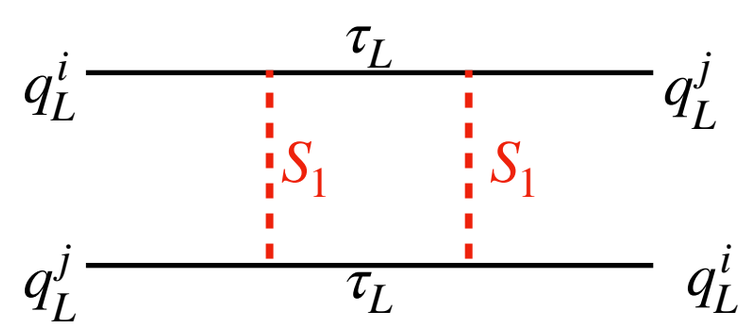
$$\mathscr{L} \supset \lambda_L (\bar{q}_L^i \epsilon \ell_L^{c3}) S_1^i + V_R^i \underbrace{\bar{b}_R^c N_R}_{\sim (V_{us},1)\,\lambda_R^b} S_1^i - M_1 S_1^{\dagger i} S_1^i$$

- No $K^+ \to \pi^+ \nu\nu$ at tree level: Possible NP in $b \to d$ transitions.



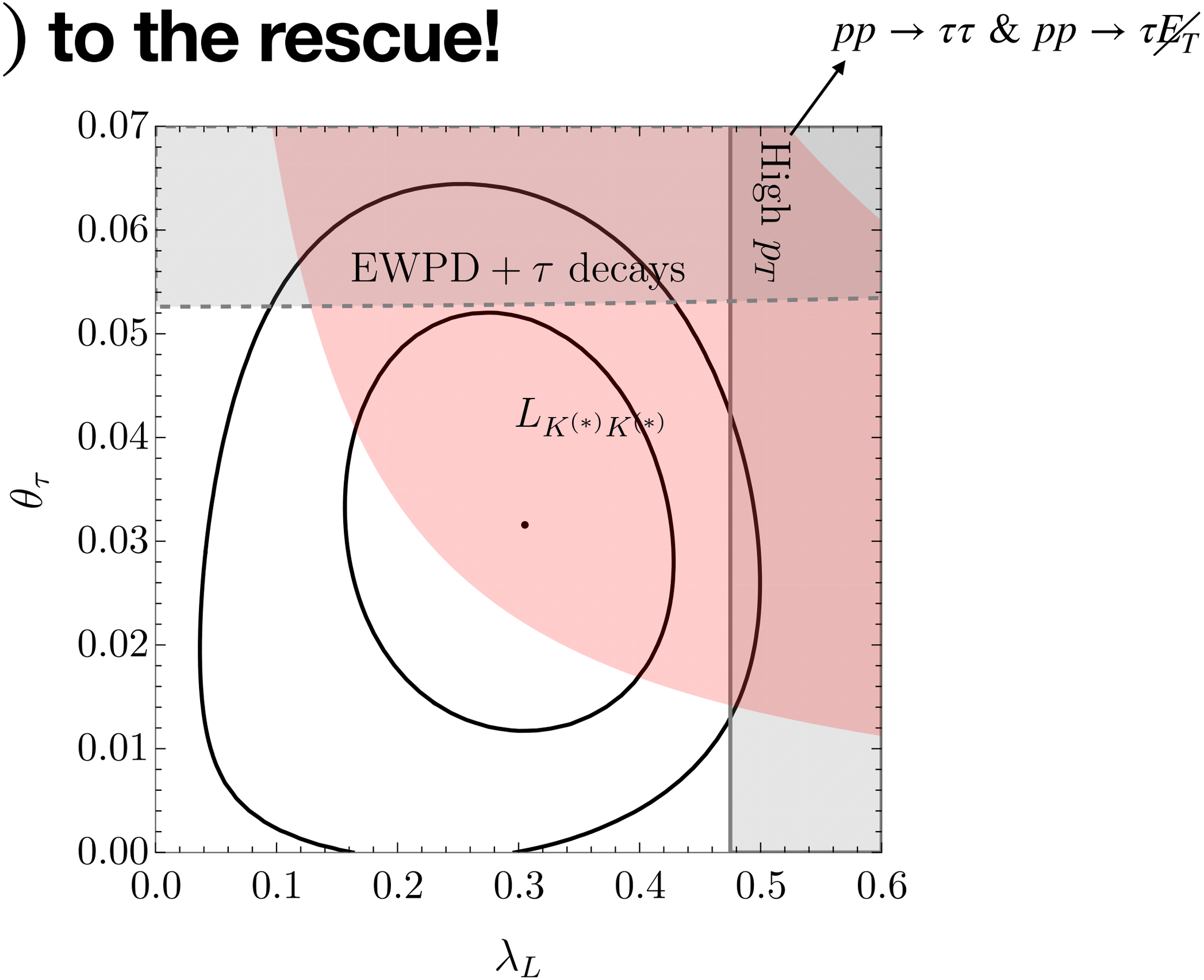
$\propto \delta_{ij}$

- Suppressed contributions $O(V_{ub}^2)$ to $D - \bar{D}$ mixing.



$\sim \delta_{ij}$

$U(2)$ to the rescue!

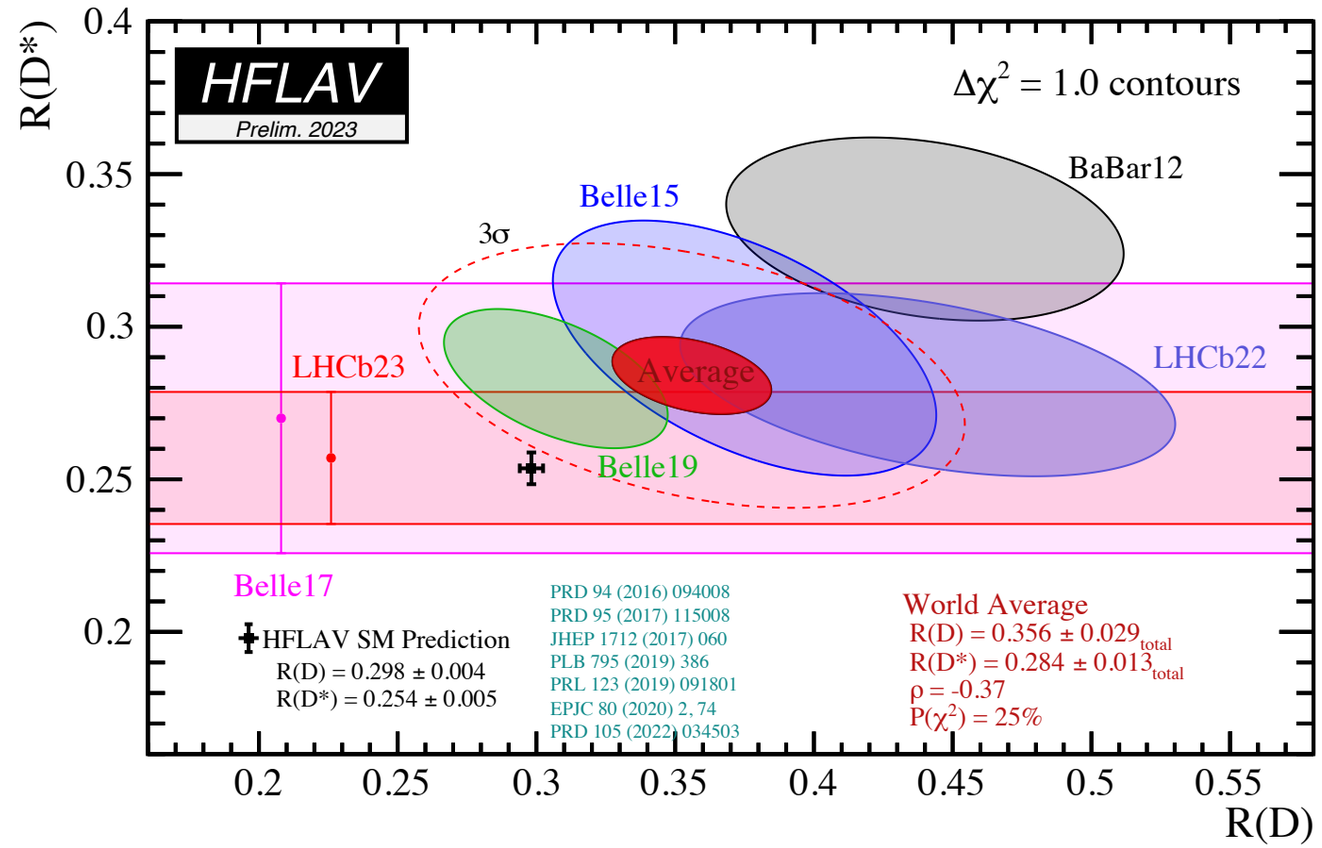


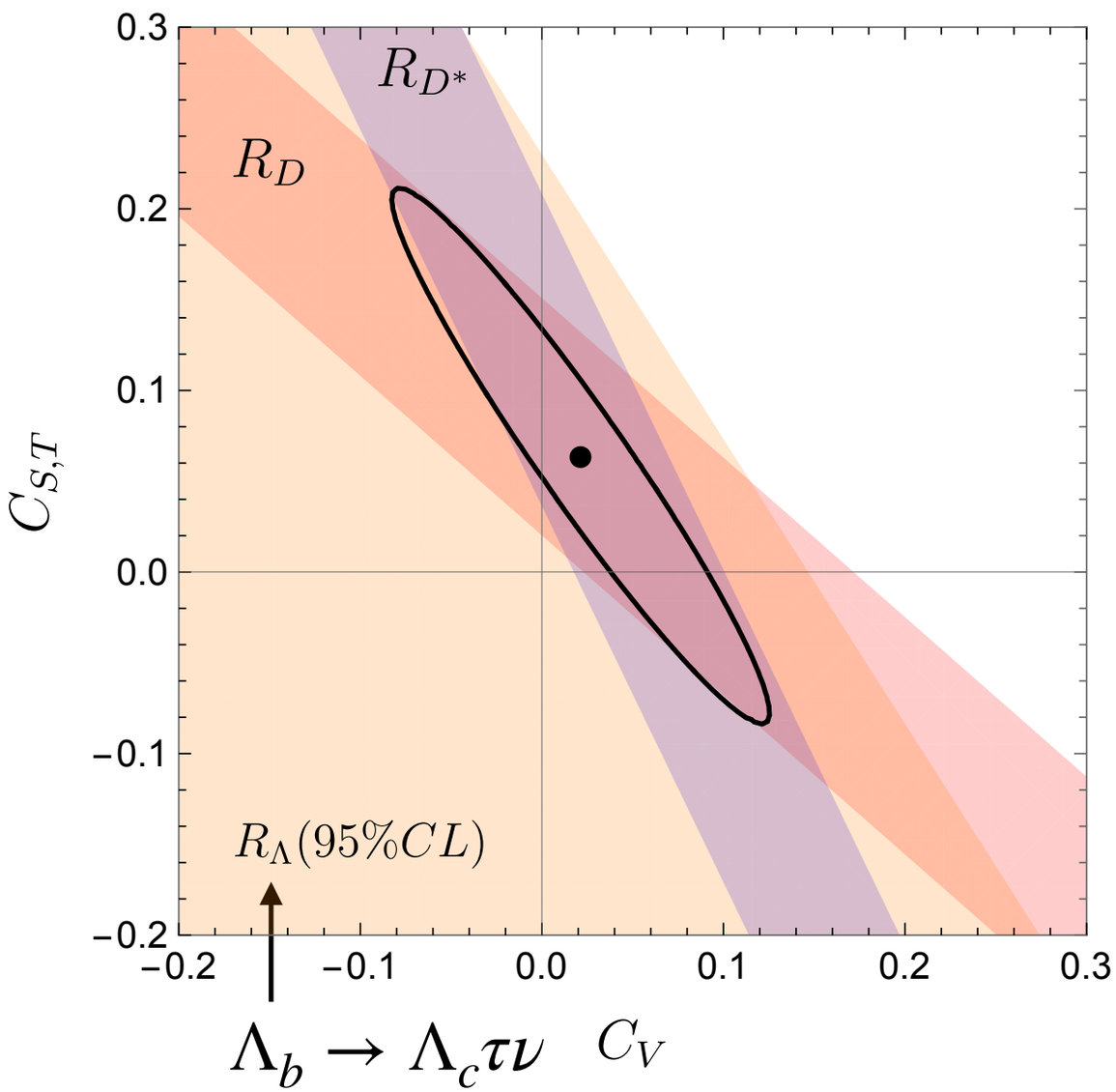
(see Ben's talk)

$b \to c\tau\nu$ data

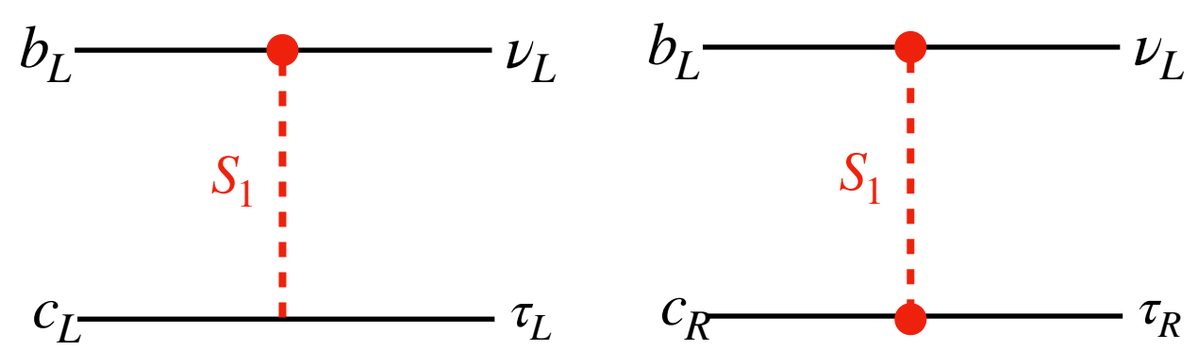
$$R_{D^{(*)}} = \frac{Br(B \to D^{(*)}\tau\nu)}{Br(B \to D^{(*)}l\nu)}$$

$\sim 3\sigma$





$$\mathscr{L} \supset \frac{2}{v_{\rm EW}^2} V_{cb}\Big[(1+C_V)(\bar{c}_L\gamma_\mu b_L)(\bar{\tau}_L\gamma^\mu\nu_L) + C_{S,T}\Big((\bar{c}_R b_L)(\bar{\tau}_R\nu_L) - \frac{1}{4}(\bar{c}_R\sigma_{\mu\nu}b_L)(\bar{\tau}_R\sigma^{\mu\nu}\nu_L)\Big)\Big]$$

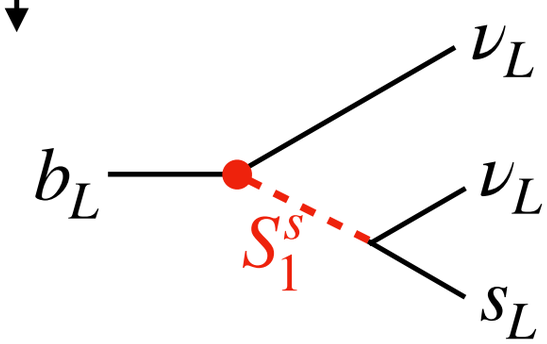


New couplings, new constraints:

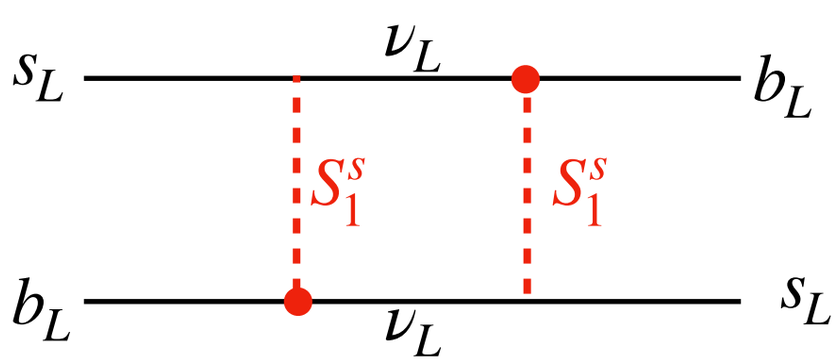
$$\mathscr{L} \supset V_L^i\,(\bar{q}_L^3 \epsilon \ell_L^{c3})\, S_1^i + \Delta_R^{ij}\, \bar{u}_R^i \tau_R^c S_1^j$$

$\sim (V_{us}, 1)\, \lambda_L^b$

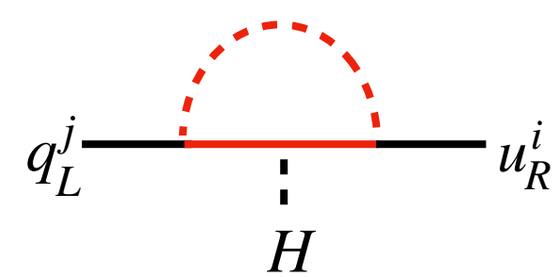
- $B \to K^{(*)}\nu\nu$



- B_s mixing



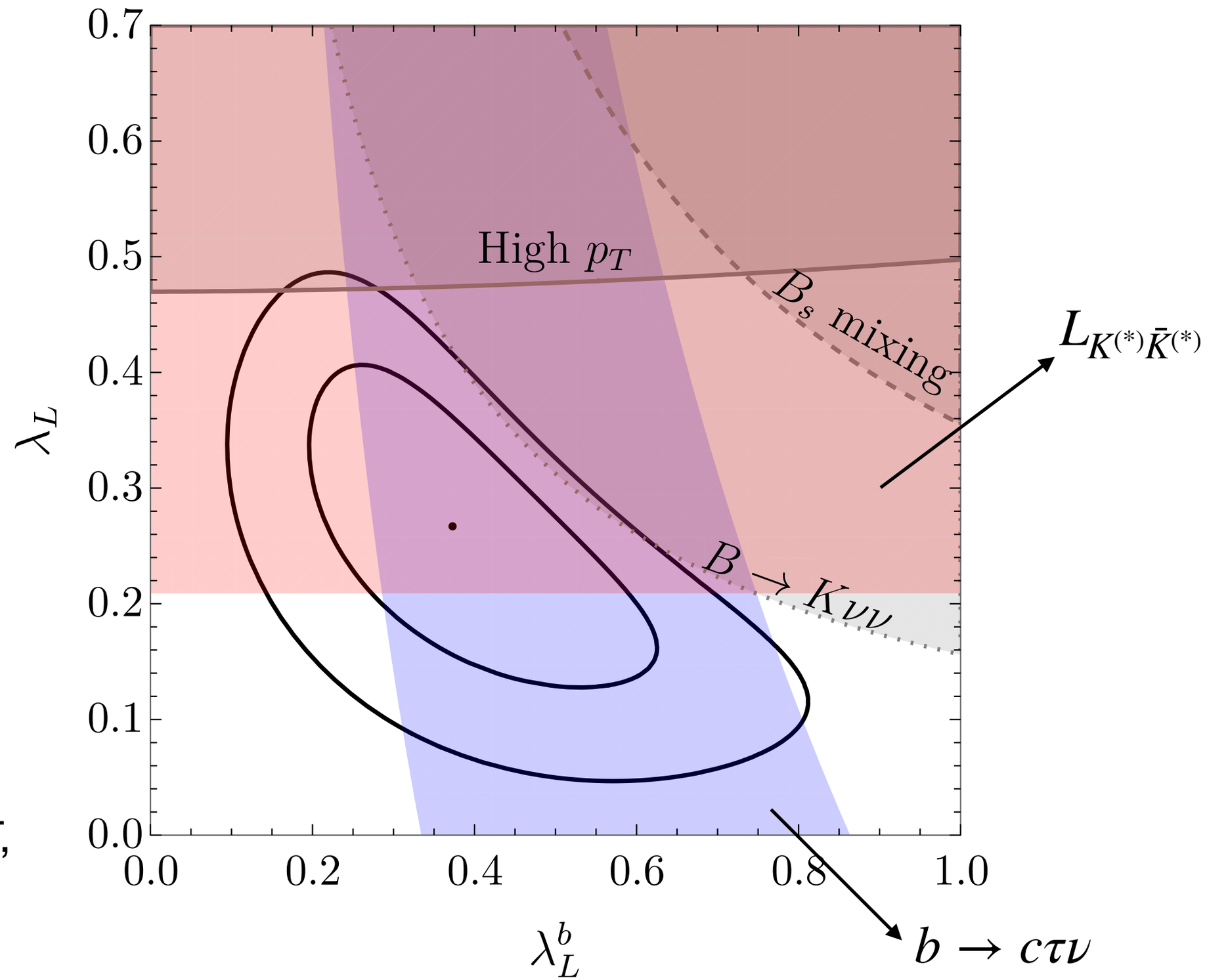
Same flavor numbers than up light Yukawas Y_u^{ij}.
Δ_R^{ij} aligned to Y_u^{ij}.
(Possible UV explanations connecting both)



Global fit

Prediction for $B \to K^{(*)}\nu\nu$: $R^{\nu}_{K^{(*)}} = 2.3 \pm 0.5$

- $L_{K^{(*)}\bar{K}^{(*)}}$
- $b \to c\tau\nu$
- $B \to K^{(*)}\nu\nu$
- B_s mixing
- High p_T :
  - $pp \to \tau\tau$
  - $pp \to \tau \not{E}_T$
- Others:
  $b \to s/d\,\gamma$, EWPT,
  τ decays, …



Conclusions

- Important deviations in non-leptonic B decays: $L_{K^{(*)}\bar{K}^{(*)}}$ observables.
- Several potential NP explanations:
    - Coloron, extra fermions and scalars, …
- A scalar leptoquark S_1 can give sizeable contributions to the bs chromodynamic dipole, and therefore it can affect the non-leptonic B decays.
- We have presented a model that can accommodate an explanation for non-leptonic and charge-current semileptonic anomalies in B decays, with connections to neutrino (and maybe quark) mass generation.

Thank you!