Z' models with less-minimal flavour violation

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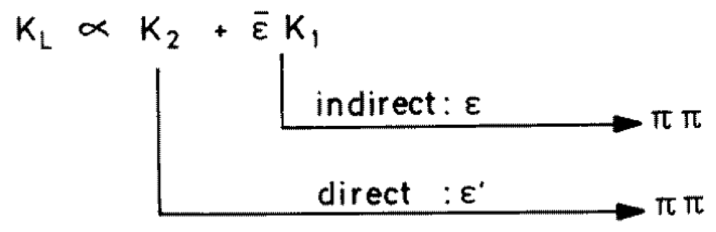
Aim

Tensions that flavour physics attempts to address:

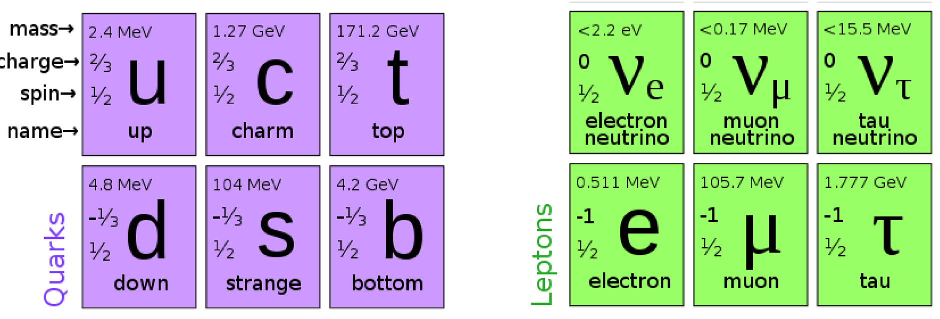
- ε'/ε:



- Z decays ($Z \to \bar{\mu}\mu$, $Z \to \bar{b}b$)
- hadronic B decays: $B \to \pi K^{(*)}$, $B \to \rho K^{(*)}$, $B_s \to \rho\phi$, $B_s \to K\overline{K}$, $B_s \to K^+K^-$
- $b \to sll$, $l = e, \mu$

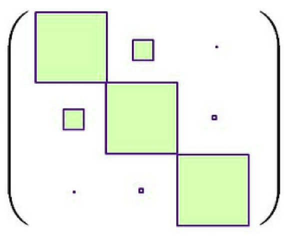
Idea:
Hierarchy betw. generations ⇒ **Correlations** betw. observables

Flavour Mixing & CP Violation in the SM

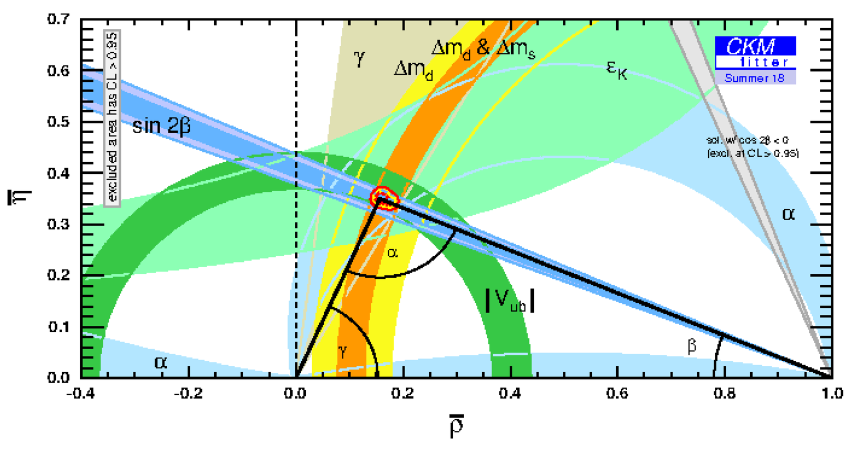


three generations ⇒ **3** angles & **1** phase, δ ⇒ **CP violation**

$$|V^{CKM}| = \left|\begin{pmatrix} c_1 & -s_1c_3 & -s_1s_3 \\ s_1c_1 & c_1c_2c_3 - s_2s_3e^{i\delta} & c_1c_2s_3 + s_2c_3e^{i\delta} \\ s_1s_2 & c_1s_2c_3 + c_2s_3e^{i\delta} & c_1s_2s_3 - c_2c_3e^{i\delta} \end{pmatrix}\right| =$$



⇑ Close to diagonal. ⇒ **Why?**



⇐ "Flat" unitarity triangle.

⇒ **Not enough CP violation** to explain baryon asymmetry of the Universe

⇒ New sources of CP violation?

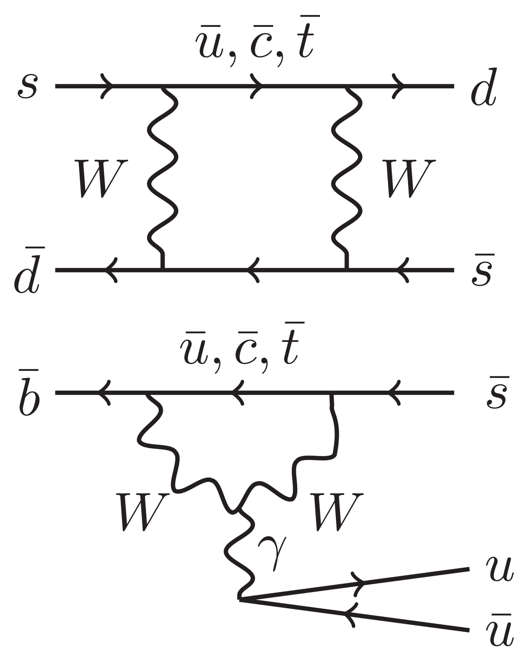
Beyond The SM: Z' models

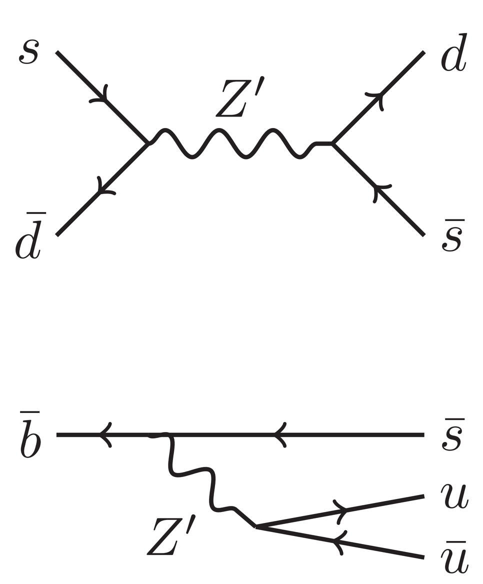
Z' models can explain ε'/ε, $B \to K\pi$ and $b \to sll$

$$\mathcal{L} = \sum_{f=u,d,\ell,\nu} \bar{f}_i\gamma^\mu \left(\Gamma_{ij}^{fL}P_L + \Gamma_{ij}^{fR}P_R\right) f_j Z'_\mu\,,$$

Simplest option: **Z' boson from a $U(1)'$ gauge group**

SM: **Z' models** :





Constraints from $\Delta F = 2$ processes (e.g. $K\overline{K}$, $B_d\overline{B}_d$ mixing)

⇒ upper bound on flavour-changing couplings to quarks:

$$\Gamma_{ij}^{u,d;L,R} < \Gamma_{ij}^{u,d;L,R}|_{max}, \quad i \neq j$$

$U(2)$ flavour symmetry ($U(2)^f$)

Large 3^{rd} generation masses ⇒ **approximate global $U(2)$ flavour symmetry**

$$U(2)^f = U(2)_Q \times U(2)_u \times U(2)_d$$

	$U(2)_Q$	$U(2)_u$	$U(2)_d$	
(Q_1, Q_2)	2	1	1	massless doublets
(u_1, u_2)	1	2	1	
(d_1, d_2)	1	1	2	
Q_3, u_3, d_3	1	1	1	heavy singlets

assumed to be respected by the gauge sector

Breaking of $U(2)$ flavour symmetry

$U(2)$ flavour symmetry can only be an **approximate** global symmetry:

- 1^{st} & 2^{nd} generation quark masses $\neq 0$
- off-diag. elements of CKM matrix are suppressed

Recipe for breaking $\mathbf{U(2)^f}$:

1. Promote the symmetry breaking parameter to a field, the **spurion**.
2. Write down **invariant terms** for these new fields.
3. The symmetry is broken **dynamically** as the new terms are switched on.

Minimal choice of spurions

The spurions Δ_u, Δ_d, X_t and X_b

	$U(2)_Q$	$U(2)_u$	$U(2)_d$
Δ_u	2	$\bar{2}$	1
Δ_d	2	1	$\bar{2}$
X_t	2	1	1
X_b	2	1	1

allow for new terms in the Yukawa Lagrangian

$$\mathcal{L}_Y = Q_i {Y^d}_{ij} d_j H + Q_i {Y^u}_{ij} u_j \tilde{H}\ , +h.c.$$

$$\frac{Y^d}{y_b} = \left(\begin{array}{cc|c} \Delta_d & & X_b \\ 0 & 0 & 1 \end{array}\right), \quad \frac{Y^u}{y_t} = \left(\begin{array}{cc|c} \Delta_u & & X_t \\ 0 & 0 & 1 \end{array}\right),$$

$y_{t,b} = \frac{m_{t,b}}{v}$ ($v \approx 174\,\text{GeV}$): Yukawa couplings of the 3^{rd} gen. quarks

Z'-couplings to quarks

Ingredients:

4 matrices diagonalising the Yukawas:

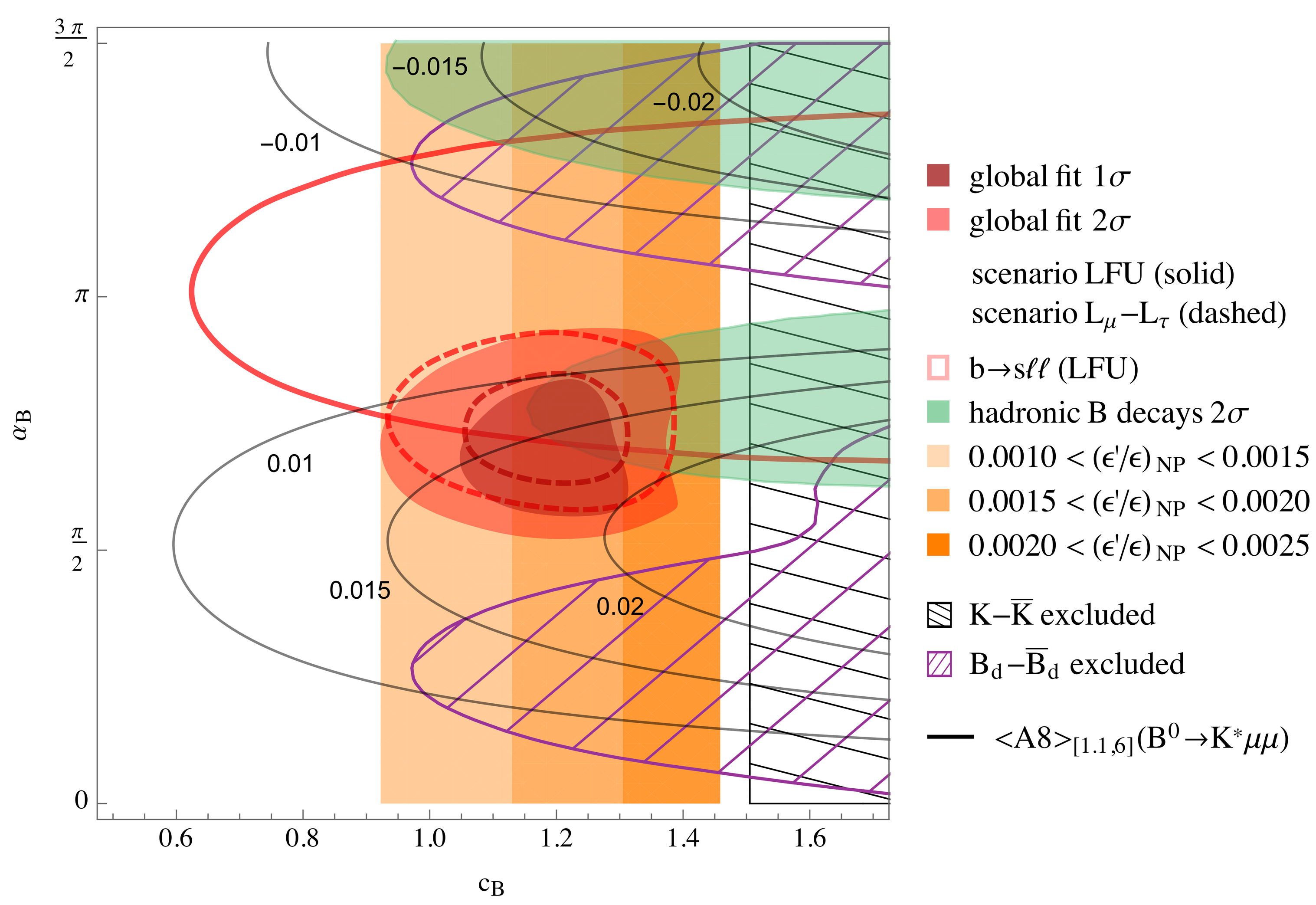
$$V^{u\dagger}Y^uW^u = \text{diag}(y_u, y_c, y_t)$$
$$V^{d\dagger}Y^dW^d = \text{diag}(y_d, y_s, y_b)$$

$U(1)'$-charges of the quarks:

$$\mathcal{Q}_Q = \text{diag}(\mathcal{Q}_{Q_{12}}, \mathcal{Q}_{Q_{12}}, \mathcal{Q}_{Q_3})$$
$$\mathcal{Q}_u = \text{diag}(\mathcal{Q}_{u_{12}}, \mathcal{Q}_{u_{12}}, \mathcal{Q}_{u_3})$$
$$\mathcal{Q}_d = \text{diag}(\mathcal{Q}_{d_{12}}, \mathcal{Q}_{d_{12}}, \mathcal{Q}_{d_3})$$

$$\Rightarrow \quad \mathbf{\Gamma^{uL} \equiv g' V^{u\dagger} \mathcal{Q}_Q V^u} \qquad \mathbf{\Gamma^{uR} \equiv g' W^{u\dagger} \mathcal{Q}_u W^u}$$
$$\mathbf{\Gamma^{dL} \equiv g' V^{d\dagger} \mathcal{Q}_Q V^d} \qquad \mathbf{\Gamma^{dR} \equiv g' W^{d\dagger} \mathcal{Q}_d W^d}$$

Final Results



Conclusion

- postulated symmetries ⇒ $U(1)'$, $U(2)^f$
- broken them in convenient ways ⇒ with spurions
- found correlations between observables that were unvisible before ⇒ simple relation between ε'/ε, hadronic B-decays and $b \to sll$!

This poster is based on arXiv:1910.00014 [hep-ph].