Flavonstrahlung at Current and Future Colliders

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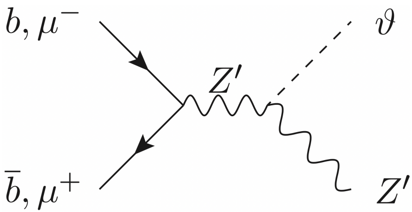


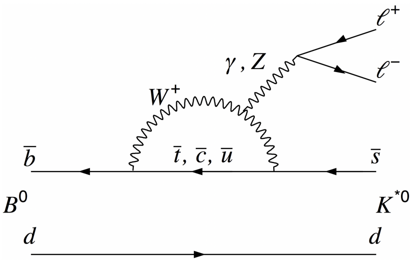
Based on arXiv:2212.07440 with Ben Allanach

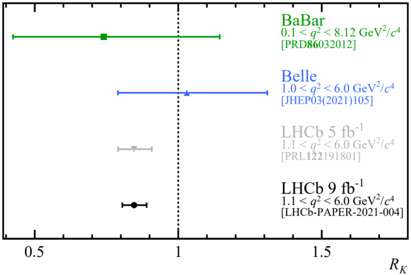
Background

Neutral current B-anomalies: disagreement between SM and experiment in processes involving $b \to s\ell\ell$ decays

Example:

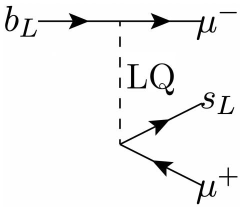
$$R_{K^{(*)}} = \frac{BR(B \to K^{(*)}\mu^+\mu^-)}{BR(B \to K^{(*)}e^+e^-)} \approx 1 \text{ in SM}$$



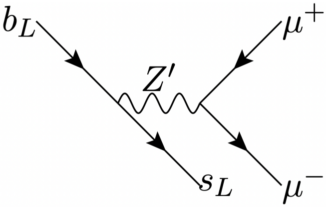


Tree-level explanations

Leptoquark models:



Z' models:



Another key motivation for flavour non-universal Z's: fermion mass puzzle[1]

[1] Allanach and Davighi, 1809.01158

$B_3 - L_2$ model[2]

Gauge group:

$$\mathcal{G} = SU(3) \times SU(2) \times U(1) \times U(1)_{B_3 - L_2}$$

Field content:

$$\text{SM} + Z' + \theta \text{ (SM singlet scalar)} + 3\nu_R$$

Spontaneous symmetry breaking:

$$\langle \theta \rangle = \frac{v_\theta}{\sqrt{2}} \sim \mathcal{O}(\text{TeV}) \Rightarrow Z' \text{ becomes massive}$$

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[2] Alonso et al., 1705.03858; Bonilla et al, 1705.00915; Allanach, 2009.02197

Fermion sector

$$\mathcal{L}_{Z'\psi} = -g_{Z'}\Big(\overline{Q'_{3L}}\not{Z}' Q'_{3L} + \overline{u'_{3R}}\not{Z}' u'_{3R} + \overline{d'_{3R}}\not{Z}' d'_{3R} - 3\overline{L'_{2L}}\not{Z}' L'_{2L} - 3\overline{e'_{2R}}\not{Z}' e'_{2R} - 3\overline{\nu'_{2R}}\not{Z}' \nu'_{2R}\Big)$$

How to connect to $b \to s\mu^+\mu^-$? We need to specify the fermion mixing matrices

$$\mathbf{P}' = V_I \mathbf{P}$$

for $I \in \{u_L, d_L, e_L, \nu_L, u_R, d_R, e_R, \nu_R\}$.

Simple mixing ansatz

Use simplicity, ease of passing bounds and ability to explain B-anomalies as a guiding principle:

$$V_{d_L} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_{sb} & -\sin\theta_{sb} \\ 0 & \sin\theta_{sb} & \cos\theta_{sb} \end{pmatrix},$$

$V_{d_R} = 1$, $V_{e_R} = 1$, $V_{e_L} = 1$ and $V_{u_R} = 1$. These imply $V_{u_L} = V_{d_L} V^\dagger_{\text{CKM}}$ and $V_{\nu_L} = U^\dagger_{\text{PMNS}}$

Now, in the mass eigenbasis:

$$\mathcal{L}_{Z'\psi} \supset -g_{Z'} \left[\left(\frac{1}{2} \sin 2\theta_{sb} \overline{s} \not{Z}' P_L b + \text{H.c.} \right) - 3\overline{\mu} \not{Z}' \mu \right]$$

Scalar potential

$$V(H,\theta) = -\mu_H^2 H^\dagger H + \lambda_H (H^\dagger H)^2 - \mu_\theta^2 \theta^* \theta + \lambda_\theta (\theta^* \theta)^2 + \lambda_{\theta H} \theta^* \theta H^\dagger H.$$

After symmetry breaking:

$$H = \begin{pmatrix} 0 \\ \frac{v_H + h'}{\sqrt{2}} \end{pmatrix}, \qquad \theta = \frac{v_\theta + \vartheta'}{\sqrt{2}}$$

$V(H,\theta) \supset -\lambda_{\theta H} v_\theta v_H h' \vartheta' \Rightarrow$ non-diagonal mass matrix

Rotate into mass eigenbasis:

$$\begin{pmatrix} h \\ \vartheta \end{pmatrix} = \begin{pmatrix} \cos\phi & -\sin\phi \\ \sin\phi & \cos\phi \end{pmatrix} \begin{pmatrix} h' \\ \vartheta' \end{pmatrix}.$$

Constraints on Higgs–flavon mixing

Higgs signal strength: $h' = \cos\phi\, h + \sin\phi\, \vartheta$
$\Rightarrow$ SM Higgs interactions scaled by $\cos\phi$

Direct flavon searches: Can use null results from SM Higgs searches at colliders to rule out light flavons

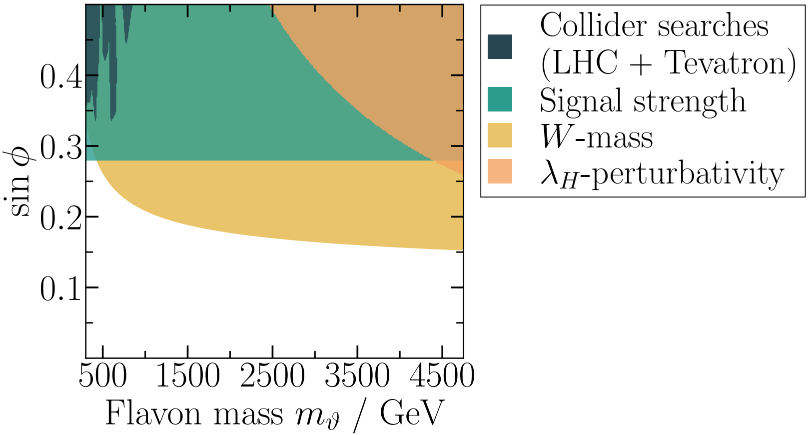
More constraints

Perturbativity: Impose $|\lambda_i| < 4\pi$

W boson mass: Take M_Z, G_F and α as experimental inputs. Obtain a (recursive) prediction for M_W:

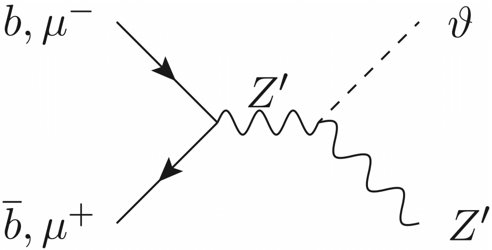
$$M_W^2 = \frac{1}{2} M_Z^2 \left[1 + \sqrt{1 - \frac{4\pi\alpha}{\sqrt{2} G_F M_Z^2} [1 + \Delta r(M_W^2)]} \right].$$

Putting it all together



How to produce the flavon?

The flavonstrahlung process:

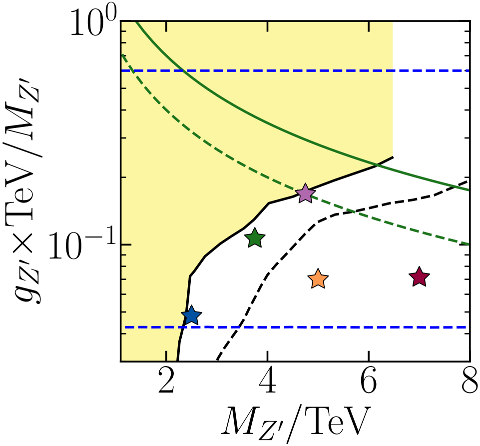


Upon further decay, $Z' \to \mu^- \mu^+$ and $\vartheta \to hh$, get resonances at $M_{Z'}$ and m_ϑ

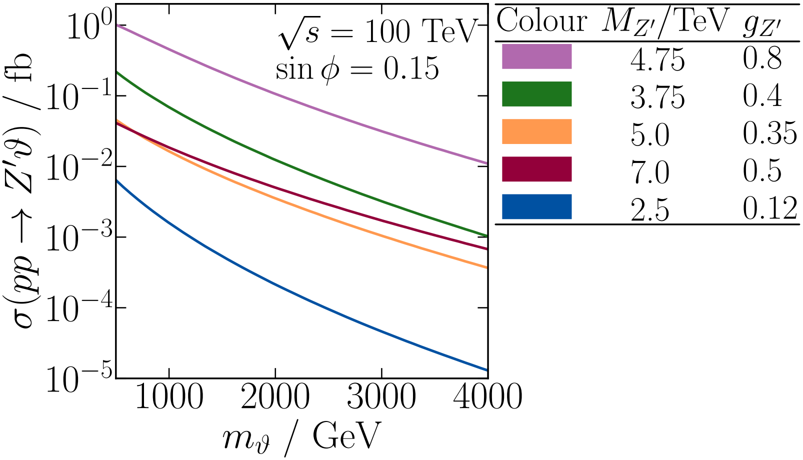
Both hadron and muon colliders of the future should have good sensitivity

Collider simulations

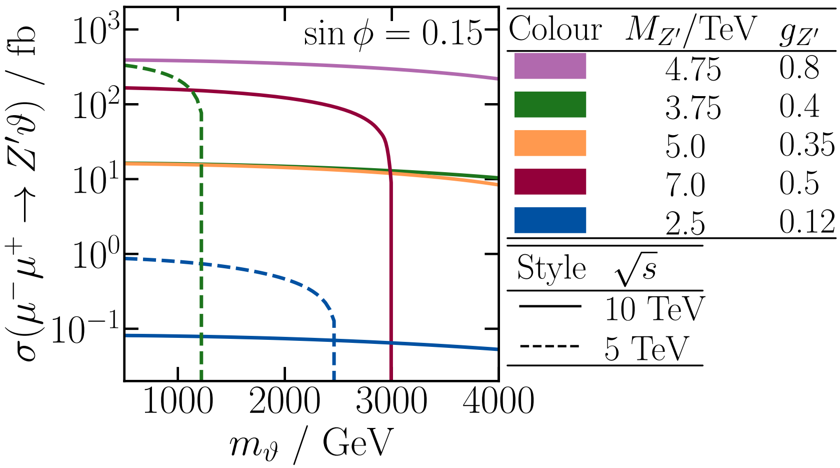
Choose benchmark points in the $M_{Z'} - g_{Z'}$ plane, compute flavonstrahlung cross-sections as a function of flavon mass



Flavonstrahlung at FCC-hh



Flavonstrahlung at muon colliders



Summary

Family non-universal Z's, such as $B_3 - L_2$, well-motivated by $b \to s\mu^+\mu^-$and fermion mass puzzle

We have studied the phenomenology of the scalar field θ and the flavonstrahlung process

Unlikely to be observed at the HL-LHC, but a 100 TeV FCC-hh or a 10 TeV muon collider would have excellent discovery prospects

The End

Thank you for listening!