On the Effects of Interference in BSM Production and Detection of diTaus at the LHC

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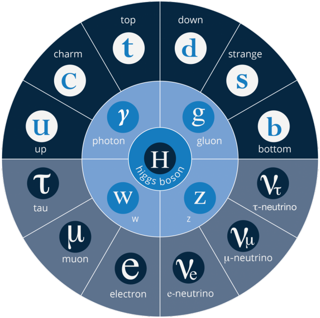
Outline

The Standard Model of Particle Physics

Weak bosons mix the different generations of quarks via the CKM matrix, but this does not happen for leptons. This property of the model is known as **lepton flavor universality (LFU)**.



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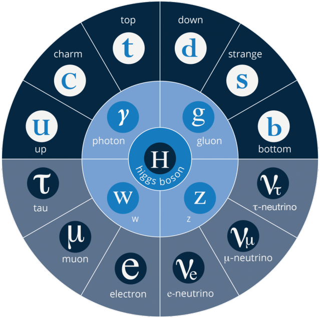
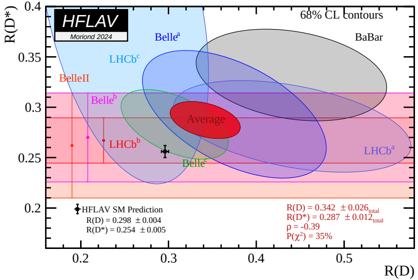
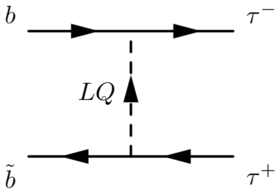
However, recent measurements of the $R(D)$ and $R(D^*)$ ratios show a deviation from the SM predictions. This could be a hint of **lepton flavor violation (LFV)** and then **new physics beyond the SM**.



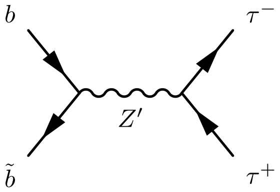


BSM Signatures in the Di-Tau Channel

Non-Resonant Production (leptoquarks)



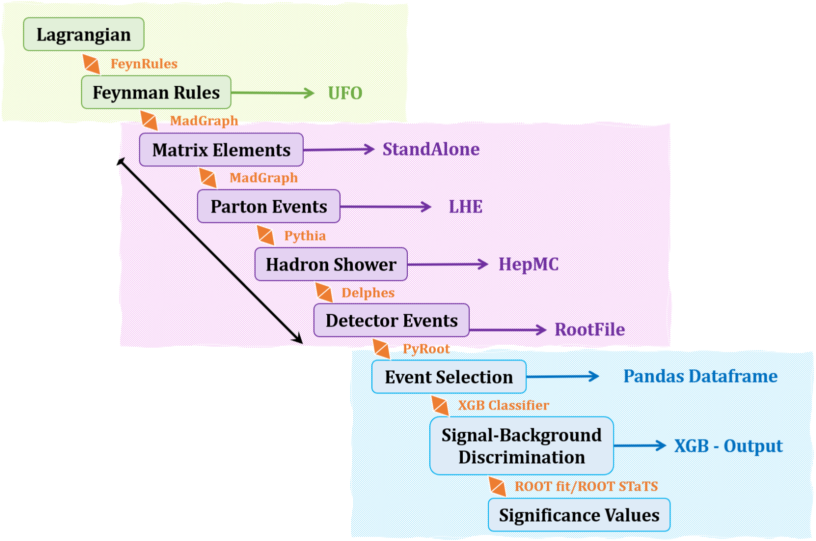
Resonant Production (neutral bosons)



Generalities of the Interference Phenomena

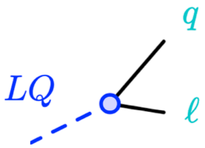
Interference Phenomena in the SM

Feasibility Studies Workflow



Example: The Vector Leptoquark Model

A leptoquark is defined as a particle with a vertex that mix vectors and quarks.



If U_1 is a vector leptoquark that preserves the chirality on the vertex, we expect an interaction term like

$$\sim U_1^\mu \bar{q}_L \gamma_\mu \ell_L,$$

and these allows a similar interaction term for the right handed currents

$$\sim U_1^\mu \bar{d}_R \gamma_\mu e_R.$$

Where the SM charges for the leptoquark, in the $Y = 2(Q - T_3)$ convention, are

	$\bar{q}_L$	ℓ_L^j	$\bar{q}_L \gamma_\mu \ell_L$	U_1^μ
$U(1)$	$-1/3$	-1	$-4/3$	$+4/3$
SU(2)	$\bar{\mathbf{2}}$	$\mathbf{2}$	$\mathbf{1}$	$\mathbf{1}$
SU(3)	$\bar{\mathbf{3}}$	$\mathbf{1}$	$\bar{\mathbf{3}}$	$\mathbf{3}$

Then, the leptoquark $U_1 \sim (\mathbf{3}_C, \mathbf{1}_I, 4/3_Y)$, and its covariant derivative is

$$\mathcal{D}_\mu U_\nu = \left(\partial_\mu + i g_s T^a G_\mu^a + i \frac{2}{3} g' B_\mu \right) U_\nu.$$

The Vector Leptoquark Lagrangian

The full Lagrangian for the vector leptoquark is

$$\begin{aligned}\mathcal{L}_U = & -\frac{1}{2}U^\dagger_{\mu\nu}U^{\mu\nu} + M_U^2 U^\dagger_\mu U^\mu \\ & - ig_s\left(1-\kappa_c\right)U^\dagger_\mu T^a U_\nu G_a^{\mu\nu} - \frac{2i}{3}g'\left(1-\kappa_Y\right)U^\dagger_\mu U_\nu B^{\mu\nu} \\ & + \frac{g_U}{\sqrt{2}}\left[U_1^\mu\left(\beta_L^{ij}\bar{q}_L^i\gamma_\mu e_L^j + \beta_R^{ij}\bar{d}_R^i\gamma_\mu e_R^j\right) + \text{ h.c. }\right]\end{aligned}$$

where $U_{\mu\nu} = \mathcal{D}_\mu U_\nu - \mathcal{D}_\nu U_\mu$, $\mathcal{D}_\mu = \partial_\mu - ig_s G^a_\mu T^a - i\frac{2}{3}g_Y B_\mu$, and the couplings β_L and β_R are complex 3×3 matrices in flavor space. If U_1 has a gauge origin $\kappa_c = \kappa_Y = 0$.

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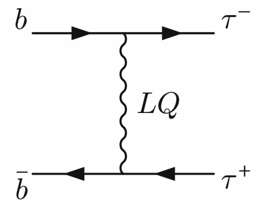
$$\psi_L^{\text{SM}} = \begin{pmatrix} q_{Lr} \\ q_{Lg} \\ q_{Lb} \\ \ell_L \end{pmatrix} \implies \mathcal{L}_{\text{int}} \sim U^\mu_{1\alpha}\bar{\psi}_L^{\text{SM}}\gamma_\mu T^\alpha_+ \psi_L^{\text{SM}} + \text{h.c.}, \quad T^\alpha_+ = \begin{pmatrix} 0 & 0 & 0 & \delta_{r\alpha} \\ 0 & 0 & 0 & \delta_{g\alpha} \\ 0 & 0 & 0 & \delta_{b\alpha} \\ 0 & 0 & 0 & 0 \end{pmatrix},$$

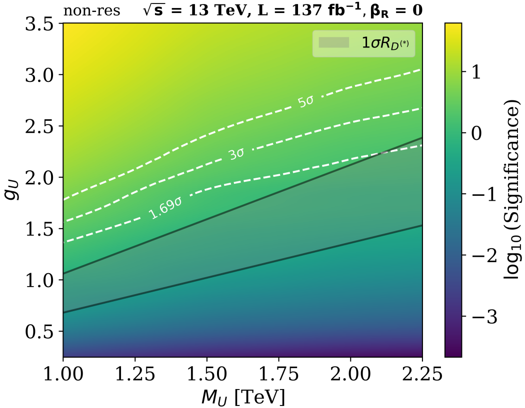
we have six generators $T^\alpha_\pm$ with closure relation,

$$\sum_\alpha \left[T^\alpha_+, T^\alpha_-\right] = 3T_{B-L} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -3 \end{pmatrix}.$$

So, the gauge group with this leptoquark must include a $U(1)_{B-L}$ symmetry. The right-handed currents also have a similar interaction term.

Sensitivity Reach of the U_1 Leptoquark





Non-resonant production is highly dependent on the couplings, so it dominates the regions of high coupling constants at all masses.

Take care, you could need a Z' boson

The generator T_{B-L} is associated with the $U(1)_{B-L}$ symmetry with a Z' boson. The interaction terms for the Z' boson have the form

$$\begin{aligned}\mathcal{L}_{\text{int}} &\sim Z'_\mu \left(\bar{\psi}_L^{\text{SM}} \gamma^\mu (3T_{B-L}) \psi_L^{\text{SM}}\right) \\ &\sim Z'_\mu \left(\bar{q}_L \gamma^\mu q_L - 3\bar{\ell}_L \gamma^\mu \ell_L\right).\end{aligned}$$

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so, the full Lagrangian for the Z' boson is

$$\begin{aligned}\mathcal{L}_{Z'} =& -\frac{1}{4} Z'_{\mu\nu} Z'^{\mu\nu} + \frac{1}{2} M_{Z'}^2 Z'_\mu Z'^\mu \\ &+ \frac{g_{Z'}}{2\sqrt{6}} Z'^\mu \left(\zeta_q^{ij} \bar{q}_L^i \gamma_\mu q_L^j + \zeta_u^{ij} \bar{u}_R^i \gamma_\mu u_R^j + \zeta_d^{ij} \bar{d}_R^i \gamma_\mu d_R^j - 3\zeta_\ell^{ij} \bar{\ell}_L^i \gamma_\mu \ell_L^j - 3\zeta_e^{ij} \bar{e}_R^i \gamma_\mu e_R^j\right),\end{aligned} \tag{1}$$

where the couplings ζ are complex 3×3 matrices in flavor space.

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We assume that both, the Z' and the vector leptoquark U_1, have preferential couplings to third generation fermions, so $\beta^{33} \gg \beta^{ij}$ and $\zeta^{33} \gg \zeta^{ij}$.

Interference with a Z' vector boson

Conclusions

Future Work