Searches of new physics in the final state $\mathrm{b}\tau_H p_T^{\mathrm{miss}}$

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Standard model of particle physics

The Standard Model of particle physics explains the interactions between the different type of particles in nature.

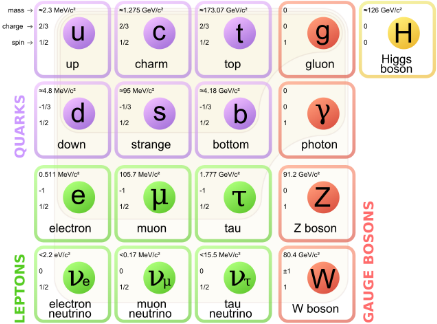
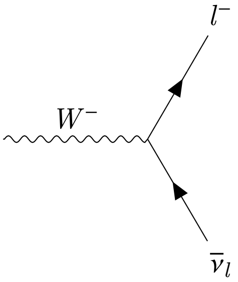


Figure: Particles in the standard model.

The Lepton Universality

If we have a process were $m_\tau \ll E$ then we can ignore the $\boldsymbol{\tau}$'s mass, the 3 charged leptons will start to look very similar.

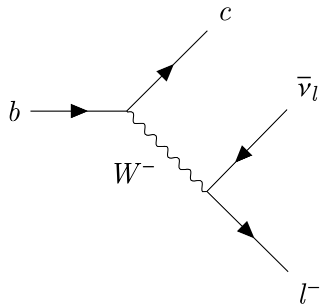


The standard model predicts that in a semi-leptonic decay of a B-meson, the Branching ratio should be the same for each lepton. [1]

[1] S. Weinberg, The quantum theory of fields. 1995

The $R_{D^{(*)}}$ Anomaly

But instead the relation between the decay to a τ and other charged lepton it's enhanced by roughly 30%[2].



$$R_{D^{(*)}} = \frac{\mathcal{B}(\bar{B} \to D^{(*)}\tau\bar{\nu}_\tau)}{\mathcal{B}(\bar{B} \to D^{(*)}l\bar{\nu}_l)} \quad (1)$$

[2] M. Huschle, T. Kuhr, M. Heck, P. Goldenzweig, A. Abdesselam. Measure-ment of the branching ratio of $\mathcal{B}(\bar{B} \to D^{(*)}\tau\bar{\nu}_\tau)$ relative to $\mathcal{B}(\bar{B} \to D^{(*)}l\bar{\nu}_l)$

The Crossing Symmetry

In particle physics if an interaction like

$$A + B \to C + D \tag{2}$$

is observed, related interactions can be anticipated from the fact that any of the particles can be replaced by its antiparticle on the other side of the interaction [3].

$$\begin{aligned} A &\to \overline{B} + C + D \\ A + \overline{C} &\to \overline{B} + D \\ \overline{C} &\to \overline{A} + \overline{B} + D \\ \overline{C} + \overline{D} &\to \overline{A} + \overline{B} \end{aligned} \tag{3}$$

[3] Michael Peskin. An introduction to quantum field theory. CRC press, 2018

Sequetial Standard Model's W′

Considering the Crossing Symmetry a alternative consideration can be made in order to explain the $R_{D^{(*)}}$

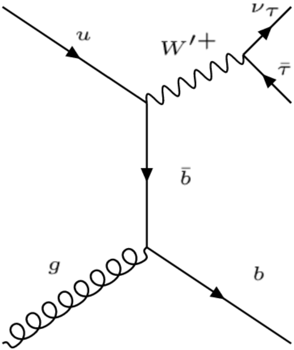


Figure: *pp* Collision with a final state of b, τ, ν mediated by a W′.

Effective Field Theory

In the case there is a heavier mediator that cannot be produced on-shell at the LHC, the *"Low Energy"* phenomenology can be studied as an EFT

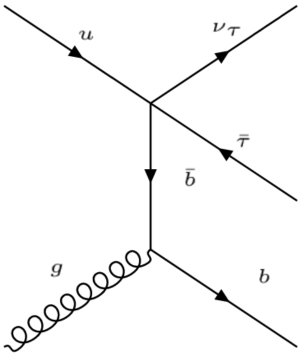


Figure: *pp* Collision with a final state of b, τ, ν with a punctual interaction

Leptoquark

In the case of the Leptoqurk (LQ) different models were tested. The best results came from considering a vectorial mediator named in literature as U_1. Where the LQ couples to the up type quarks and the neutral leptons, and to the down type quarks in company with the charged leptons.

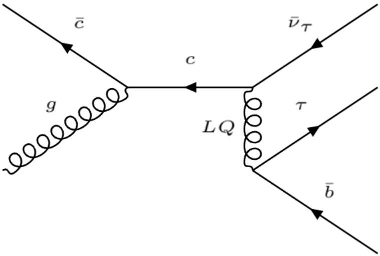


Figure: pp Collision with a final state of b, τ, ν Mediated via a LQ.

The Simulation

Different simulations were made for each signal (W′, EFT and LQ) and backgrounds ($t\bar{t}$ semileptonic, W + Jets and Z + Jets).
The software used were:

1. **MadGraph5** for parton simulation and cross section calculation.
2. **Pythia8** for hadronization simulation process
3. **Delphes** for detectors response emulation.

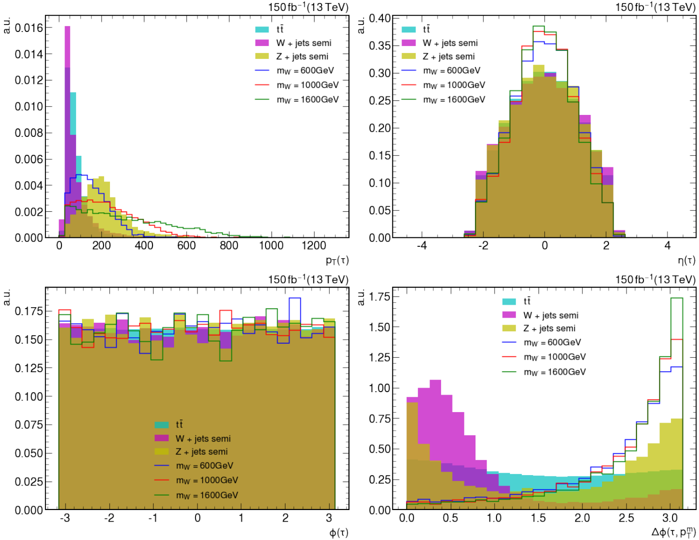
Simulation and Cross Section

Simulations' Models were made according with the reference [4].

Model	Parameters	Cross Section(pb)
W'	$m_{W'} = 6 \times 10^2$GeV	5.25
	$m_{W'} = 1 \times 10^3$GeV	0.45
	$m_{W'} = 1.6 \times 10^3$GeV	0.03
EFT	$\epsilon_l^{cb} = 1.0$	0.13
	$\epsilon_{sL}^{cb} = 1.0$	0.08
	$\epsilon_t^{cb} = 1.0$	0.71
LQ	$m_L Q = 1 \times 10^3$ GeV	0.02
	$m_L Q = 2 \times 10^3$ GeV	3×10^{-4}
	$m_L Q = 3 \times 10^3$ GeV	9.82×10^{-6}

[4] A. Greljo, J. M. Camalich, and J. D. Ruiz- Alvarez, Mono-τ signatures at the lhc constrain explanations of b-decay anomalies, Physical review letters122, 131803 (2019)

Kinematics


150 fb^{-1}(13 TeV)
a.u.
$t\bar{t}$
W + jets semi
Z + jets semi
m_W = 600GeV
m_W = 1000GeV
m_W = 1600GeV
$p_T(\tau)$
$\eta(\tau)$
$\phi(\tau)$
$\Delta\phi(\tau, p_T^m)$

Significances

A baseline selection was made according to the reference [5] requesting events that satisfies.

Criterion	Selection
$N(\tau_h)$	> 0
$\|\eta_\tau\|$	≤ 2.3
Veto $2^{\text{nd}} - \tau_h$	$p_{\text{T}} > 50$ GeV & $\|\eta\| < 2.3$
$N_{e/\mu}$ with $p_T(e/\mu) > 15$ GeV	$= 0$
$N_{\text{b-jets}}$	$= 1$
$p_{\text{T}}(\text{b})$	> 20 GeV
$\|\eta_{\text{b-jets}}\|$	< 2.5

Table: Baseline selection criteria common for the 3 different models.

[5] Mohammad Abdullah, Julian Calle, Bhaskar Dutta, Andres Florez, and Diego Restrepo. Probing a simplified W model of $R_{D^{(*)}}$ anomalies using b tags, τ leptons, and missing energy. Physical Review D, 98(5):055016, 2018.

Analysis parameters

In order to maximize the statistical significance

$$Z = \frac{N_s}{\sqrt{N_s + N_b}} \tag{4}$$

straight cuts are made to be above:

Parameter	W'	EFT	LQ
$p_T(\tau)$	250 GeV	200 GeV	300 GeV
$\lvert\Delta\phi(\tau, \mathbf{p}_T^{\text{miss}})\rvert$	2	2.0	1
p_T^{miss}	200 GeV	300 GeV	400 GeV

Table: Parameters Table.

τ Transverse Mass(W')

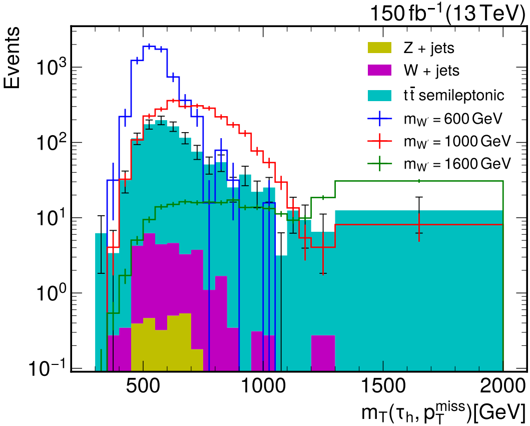


Figure: τ_h Transverse Mass

τ, b, $\mathrm{p}_T^{\mathbf{miss}}$ Total Mass(EFT)

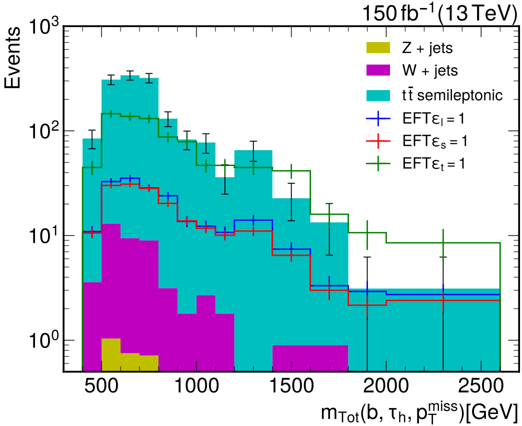


Figure: Total Mass between τ_h , b, MET

b, τ_h Invariant Mass($U1_{LQ}$)

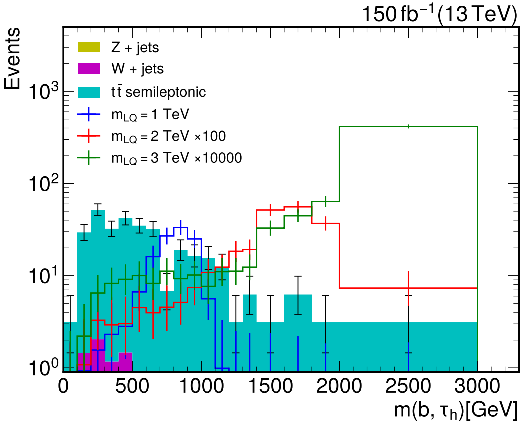


Figure: Invariant Mass between τ_h and b

Significances at $\sqrt{s} = 13$ TeV

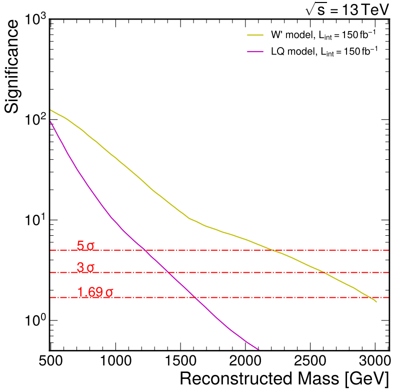


Figure: W' and LQ masses in the horizontal axis, and the Significance in the vertical axis. The horizontal lines are the 1.69σ, 3σ exclusion value and the 5σ for NP.

Significances at 13.6 TeV

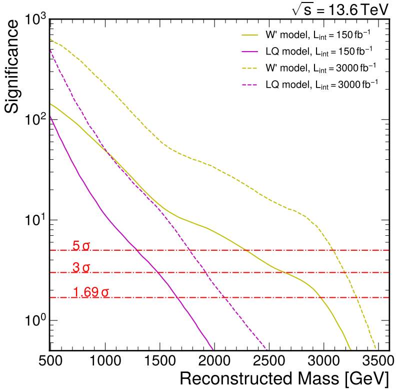


Figure: W' and LQ masses in the horizontal axis, and the Significance in the vertical axis. The horizontal lines are the 1.69σ, 3σ exclusion value and the 5σ for NP.

EFT Significance

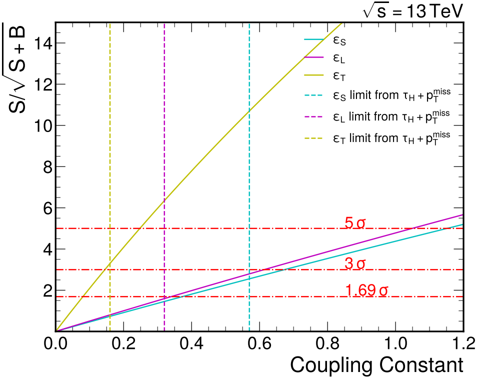


Figure: EFT coupling values in the horizontal axis, and the Significance Z in the vertical axis. The horizontal lines are the exclusion and NP values.

Conclusions and projections

- This proposal covers a new signature which must exist if a W′ is the responsible for the $R_{(*)}$ anomalies.
- The signature considered in this work is a novel signature to search for LQs with more sensitivity to other similar studies related with LQs and τs.
- In the EFT channel, the limits reached using $b + \tau_h + p_T^{miss}$ signature are competitive with the $\tau_h + p_T^{miss}$ results.
- An analysis for the same final state could be developed with ML techniques in order to compare the scope with that achieved in this modular analysis.
- The search can be made at an experimental level in colliding experiments as CMS or ATLAS.


Yo: Mama no encuentro señales de física más allá del modelo estandar
Mi mamá: ¿Y si yo las encuentro qué te hago?

Thank you!