

# Searches of new physics in the final state $B$ - $\tau$ -MET

Tomas Atehortua José D. Ruiz

Instituto de Física  
Facultad de Ciencias Exactas y Naturales  
Universidad de Antioquia

E-mail: [tomas.atehortua@udea.edu.co](mailto:tomas.atehortua@udea.edu.co)



UNIVERSIDAD  
DE ANTIOQUIA

1 8 0 3

CMS Collaboration  
CERN

December 3, 2021



# Outline I

## 1 Introduction

- Standard Model of particle physics

## 2 Problem

- The Lepton Universality
- The  $R_{D^{(*)}}$  Anomaly
- The Crossing Symmetry

## 3 Topologies

- Sequential Standard Model's  $W'$
- Effective Field Theory
- Leptoquark

## 4 Softwares

- The Simulation

## 5 Parameters

4.8%

# Outline II

- Simulation
- Kinematics
- Analysis parameters

## 6 Results

- Sequential Standard Model's  $W'$
- EFT
- Leptoquark

## 7 Conclusions

# Standard Model of particle physics

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

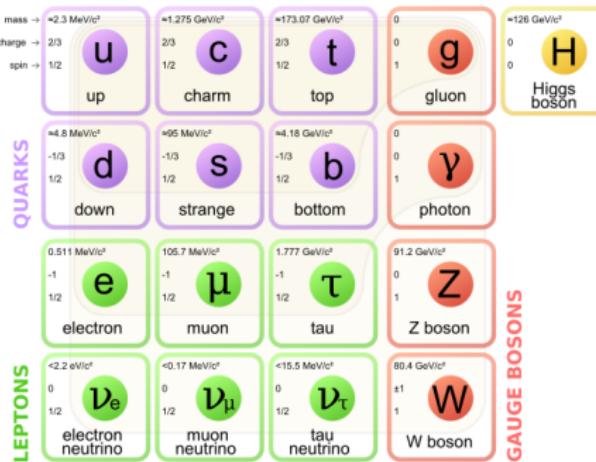
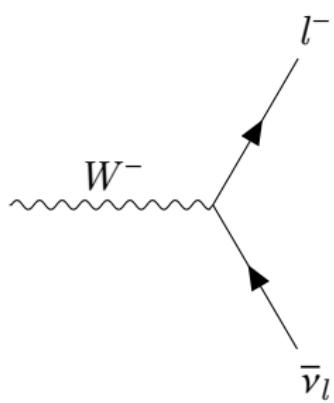


Figure: Particles in the standard model.

# The Lepton Universality

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



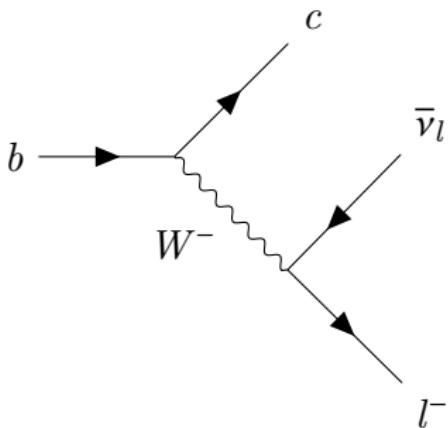
The standard model predicts that in a semi-leptonic decay of a  $B$ -meson, the Branching ratio should be the same for each lepton.<sup>1</sup>

---

<sup>1</sup>S. Weinberg, The quantum theory of fields. 1995

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

But instead the relation between the decay to a  $\tau$  and other charged lepton it's enhanced by roughly 30%<sup>2</sup>.



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

---

<sup>2</sup>M. Huschle, T. Kuhr, M. Heck, P. Goldenzweig, A. Abdesselam.

Measurement of the branching ratio of  $\mathcal{B}(\bar{B} \rightarrow D^{(*)}\tau\bar{\nu}_\tau)$  relative to  $\mathcal{B}(\bar{B} \rightarrow D^{(*)}l\bar{\nu}_l)$  23.8%

# The Crossing Symmetry

In particle physics if an interaction like

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

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 <sup>3</sup>.

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

---

<sup>3</sup>Michael Peskin. An introduction to quantum field theory. CRC press, 2018 28.6%

# Sequelial Standard Model's $W'$

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

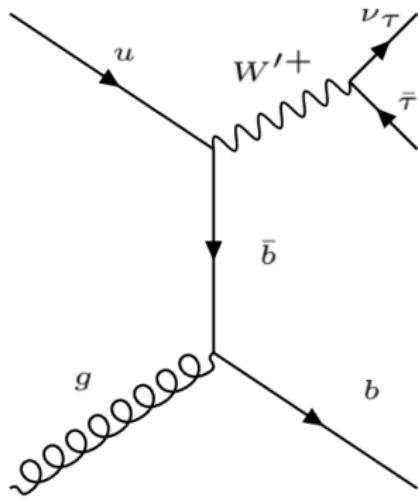


Figure:  $pp$  Collision with a final state of  $b, \tau, \nu$  mediated by a  $W'$ .

# 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

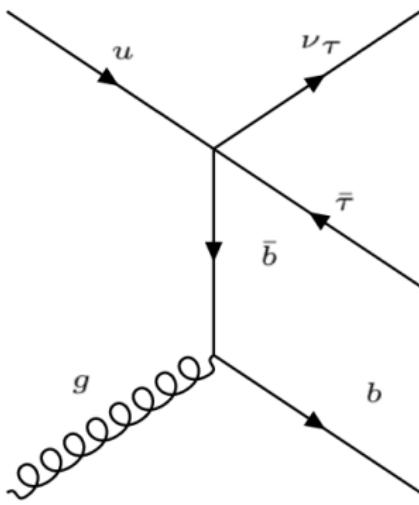


Figure:  $pp$  Collision with a final state of  $b, \tau, \nu$  with a punctual interaction

# Leptoquark

In the case of the Leptoquark (LQ) different models were tested. The best results came from considering a  $U(1)$ . Where the LQ. Couples to the up type quarks and the neutral leptons, and to the down quarks in company with the charged leptons

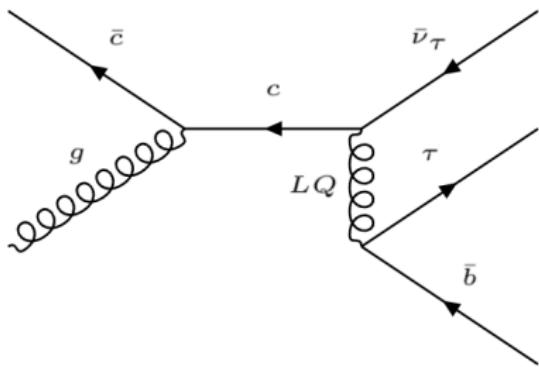


Figure:  $pp$  Collision with a final state of  $b, \tau, \nu$  Mediated via a LQ.

# The Simulation

Different simulations were made for each signal ( $W'$ , EFT and LQ) and backgrounds ( $t\bar{t}$  semileptonic, Jets +  $W \rightarrow \tau + \nu$  and Jets +  $Z \rightarrow \tau + \bar{\tau}$ ). 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.

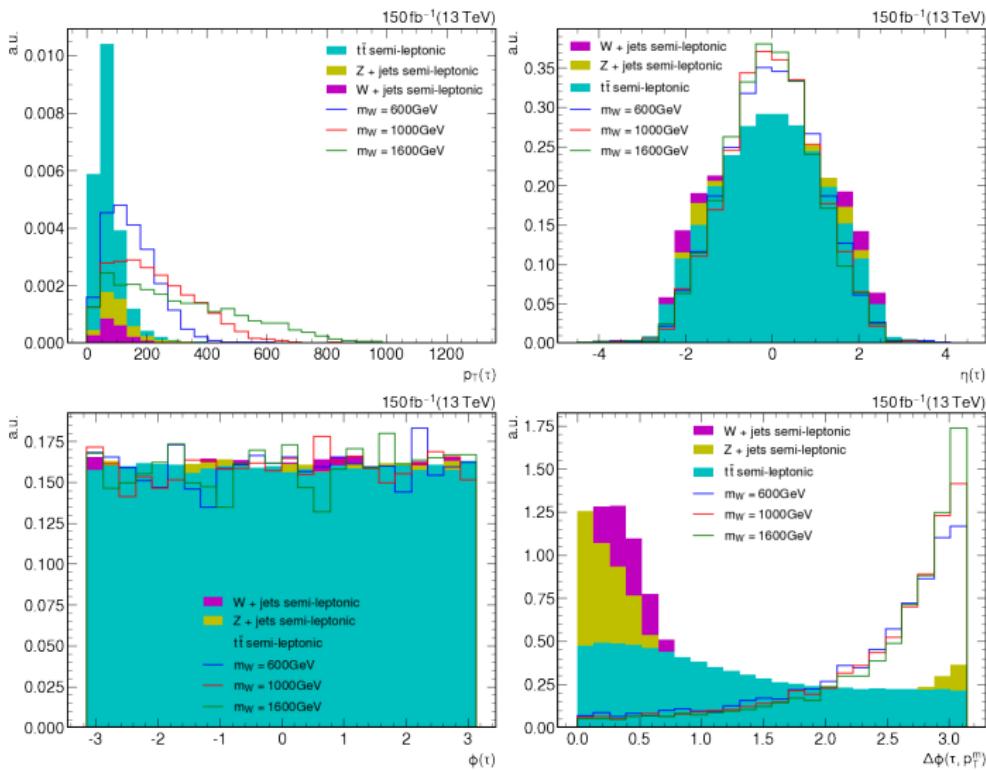
# Simulation and Cross Section

Simulations' Models were made according with the reference <sup>4</sup>.

| Signal                       | Cross Section                   |
|------------------------------|---------------------------------|
| $m_{W'} = 0.6 \text{ TeV}$   | 5.25 pb                         |
| $m_{W'} = 1.0 \text{ TeV}$   | 0.45 pb                         |
| $m_{W'} = 1.6 \text{ TeV}$   | 0.03 pb                         |
| EFT $\epsilon_L^{cb} = 1$    | 0.13 pb                         |
| EFT $\epsilon_T^{cb} = 1$    | 0.71 pb                         |
| EFT $\epsilon_{SL}^{cb} = 1$ | 0.08 pb                         |
| $m_{LQ} = 1.0 \text{ TeV}$   | 0.02 pb                         |
| $m_{LQ} = 2.0 \text{ TeV}$   | $3.0 \times 10^{-4} \text{ pb}$ |
| $m_{LQ} = 3.0 \text{ TeV}$   | $9.8 \times 10^{-6} \text{ pb}$ |

<sup>4</sup>A. Greljo, J. M. Camalich, and J. D. Ruiz- Alvarez, Mono- $\tau$  signatures at the lhc constrain explanations of b-decay anomalies, Physical review letters 122, 131803 (2019)

# Kinematics



# Significances I

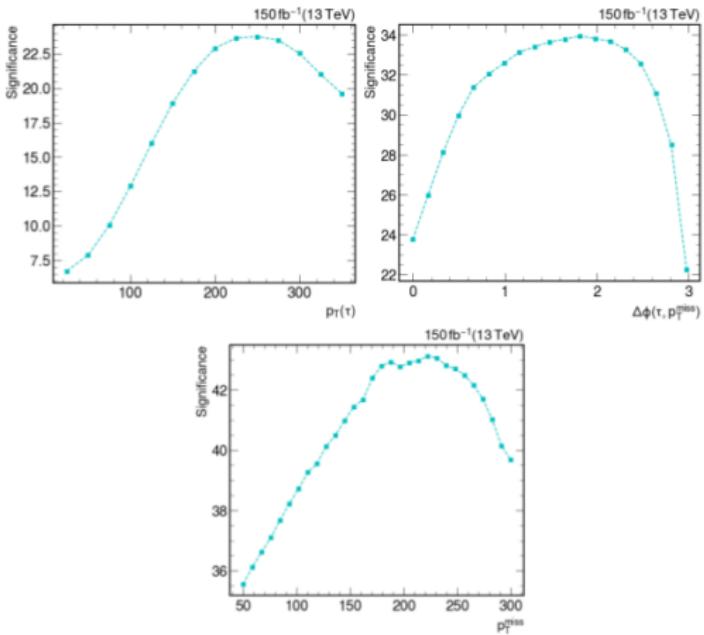


Figure: Sequential Standard Model significance curve.

# Significances II

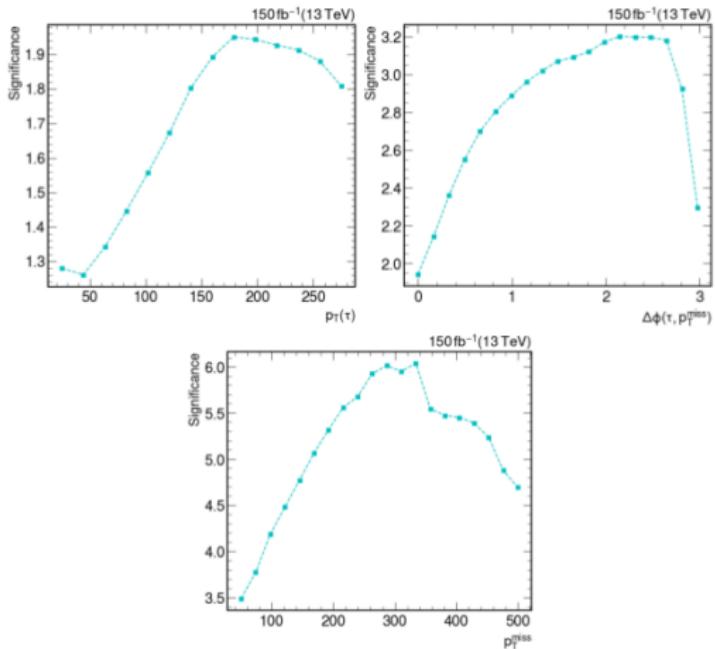


Figure: Effective Field Theory significance curve.

# Significances III

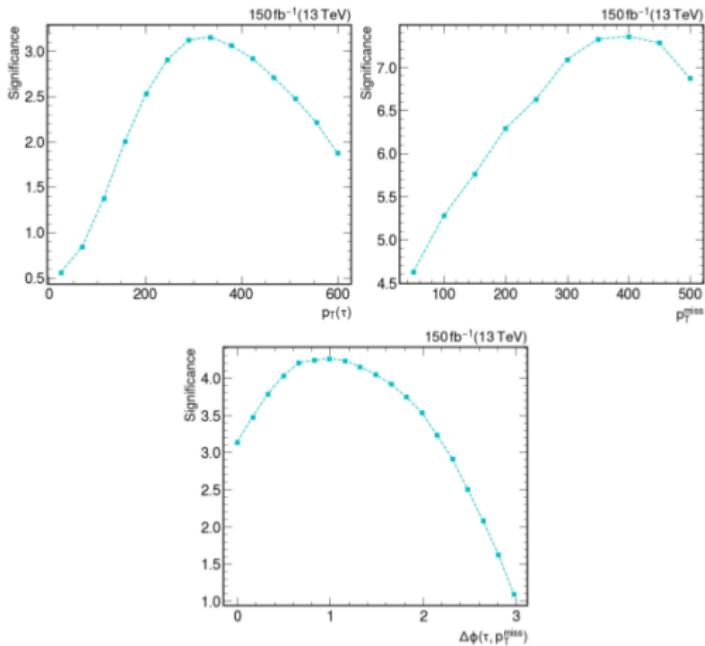


Figure: Leptoquark model significance curve.

# Analysis parameters

In order to maximize the statistical significance

$$Z = \frac{N_s}{\sqrt{N_s + N_b}} \quad (4)$$

straight cuts are made to be above:

| Parameter  | SSM     | EFT     | $U(1)_{LQ}$ |
|--|---------|---------|-------------|
| $p_T(\tau)$                                      | 250 GeV | 200 GeV | 300 GeV     |
| $ \Delta\phi(\tau, \mathbf{p}_T^{\text{miss}}) $ | 2       | 2.0     | 1           |
| $\mathbf{p}_T^{\text{miss}}$                     | 200 GeV | 300 GeV | 400 GeV     |
| Reached Significance                             | 43      | 6.0     | 7.5         |

Table: Parameters Table.

# $\tau$ Transverse Mass(SSM)

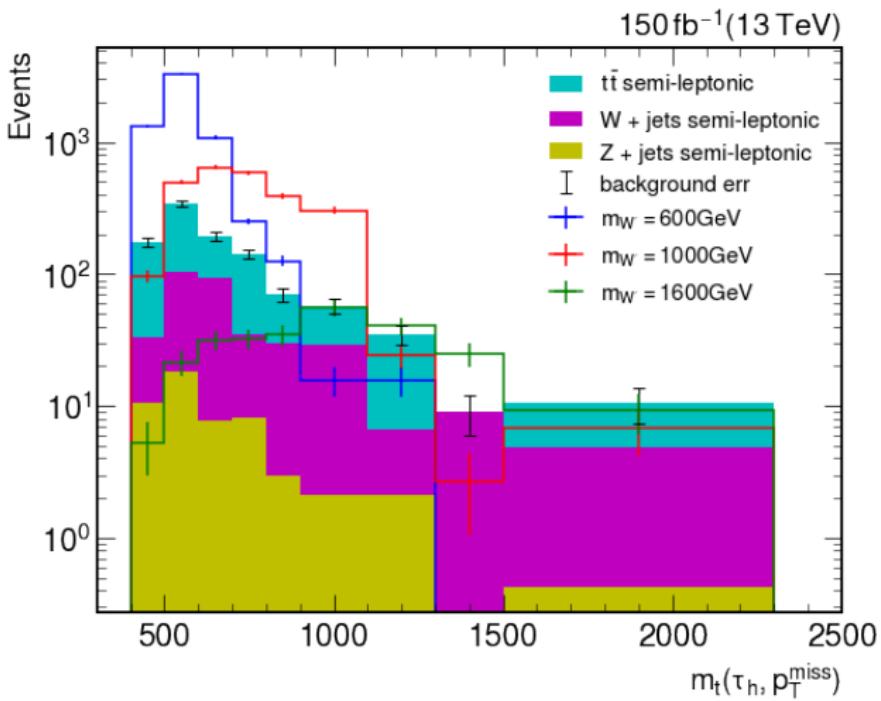
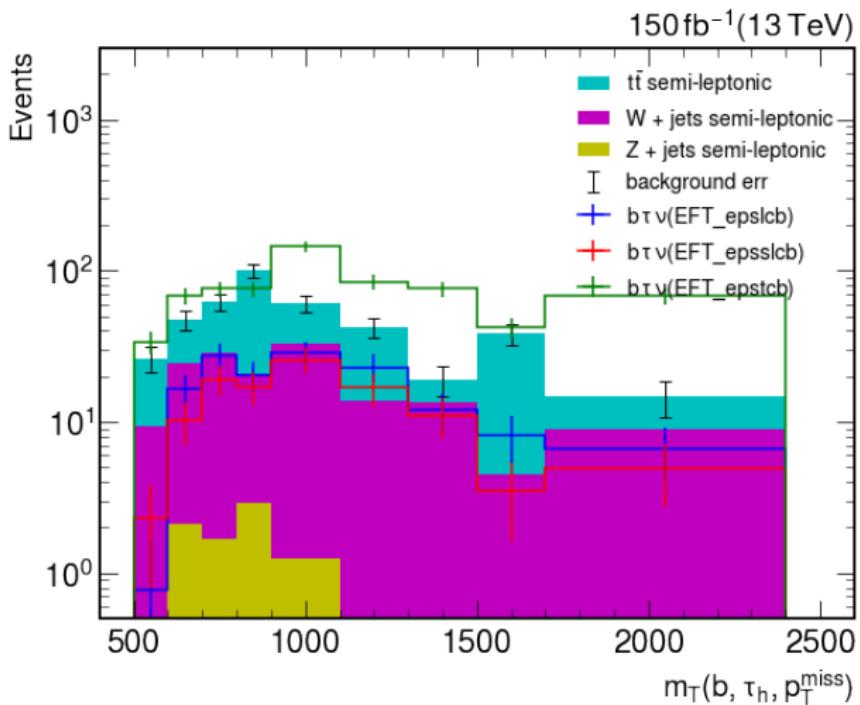


Figure:  $\tau_h$  Transverse Mass

$\tau, b, p_T^{\text{miss}}$  Total Mass(EFT)Figure: Total Mass between  $\tau_h$ ,  $b$ , MET

# $b, \tau_h$ Invariant Mass( $U(1)_{LQ}$ )

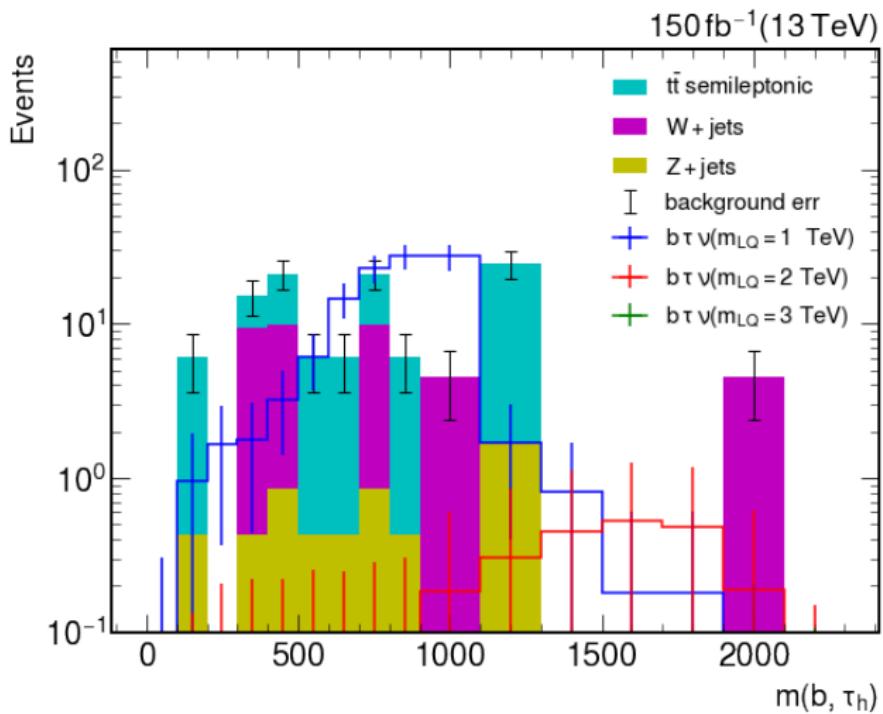


Figure: Invariant Mass between  $\tau_h$  and  $b$

# Conclusions and projections

- The  $R_{D^{(*)}}$  anomaly can be explained if there would be signals of physics BSM.
- The exclusions limits are reached for the 3 models.
- The search can be made at an experimental level in colliding experiments in CMS or ATLAS.



*Thank you!*