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Searches for New Physics With Tau Leptons at the CMS Experiment

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Abstract

The Standard Model of Particle Physics is currently the best model of the fundamental particles and their interactions. However, there are still significant theoretical issues and recently seen experimental tensions with the model. The theoretical issues include the hierarchy problem which forecasts the breakdown of the Standard Model when looking at the size of corrections needed to calculate the mass of the newest found member of the theory, the Higgs boson particle. The current experimental tensions include the B-anomalies and the g-2 measurement. These results, although they do not yet sit at the required 5σ deviation for a discovery, offer the most prominent leads into where new physics may be hiding. Looking for signatures of theoretical explanations of these anomalies offers excellent search options for new fundamental particles. This thesis describes the search for new physics that can explain both the theoretical problems and experimental tensions. This is done using tau leptons seen during Run-2 of the Large Hadron Collider (LHC) at the Compact Muon Solenoid (CMS) experiment. The Beyond Standard Model theories searched for range from Supersymmetry, leptoquarks, to type-X two Higgs doublet models. Each theory is separately studied and an analysis is tailored to find its most sensitive signature. In the process of optimisation, data-driven background modelling is improved to aid the reliability of the results. The results are currently blinded however the expected limits offer some of the largest constraints that are placed on these prominent Beyond Standard Model Theories.

Declaration

I did this work I promise

Acknowledgements

Emmeline

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Chapter 1

Searches for New Physics in $\tau^+\tau^-$ Final States

1.1 Introduction

The $\tau\tau$ final states are powerful tool to search for new physics at colliders. As the heaviest lepton, they are sensitive to resonant production of new neutral particles where the couplings have mass hierarchy. They are also sensitive to non-resonant effects from new physics mediators. This chapter will detail the searches for two such areas of new physics: additional Higgs bosons and vector leptoquarks. These searches are split up into three sections:

i A model independent search for single narrow spin-0 resonance, ϕ, produced via gluon fusion (ggϕ) or in association with a bottom quark (bbϕ). The SM Higgs boson is treated as a background. The quark contents of the gluon fusion loop are set to that of the SM Higgs boson.

ii A search for the t-channel exchange of a U_1 vector leptoquark. Two scenarios are taken, based of the best fit to the b anomalies. These scenarios are detailed in Section 1.1.2.

iii A search for the MSSM Higgs sector, in a number of benchmark scenarios. The benchmark scenarios are defined in Section 1.1.1. The production of SM Higgs boson is also used to constrain the available phase space.

1.1.1 Additional Higgs Bosons

Extended Higgs sectors, such as that of the MSSM, can be probed by direct searches for the additional bosons and further precise measurements of the Standard Model

Higgs boson. This search for an extended Higgs sector is motivated by Type II 2HDMs, such as the MSSM. In these models $\tan\beta$ enhances couplings of additional Higgs bosons to b-like quarks and leptons, whilst top-like couplings are suppressed. This narrows down the most important production modes of the Higgs boson into two categories: Gluon fusion and production in association with a b quark. Examples of these are shown in Figure 1.1.

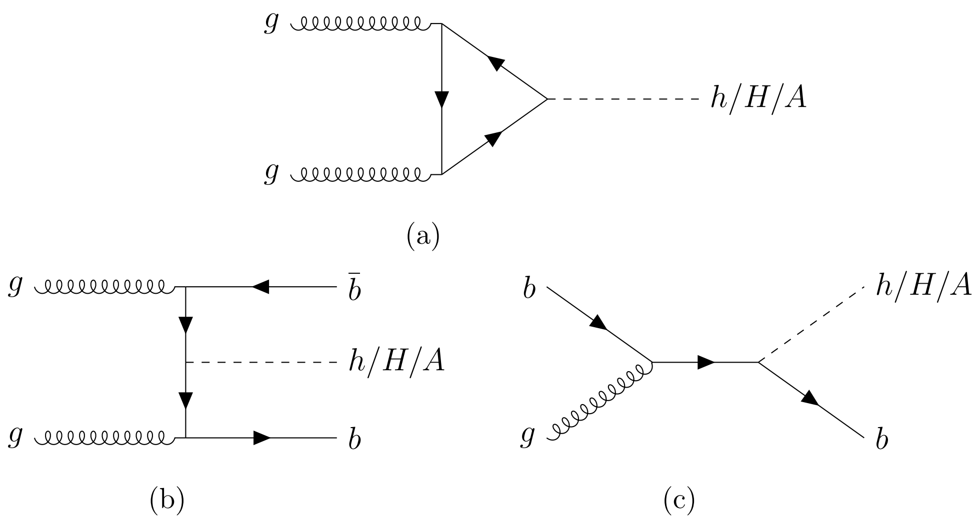


Figure 1.1: Diagram (a) shows the production of neutral Higgs bosons from gluon fusion. The dominant loop contributions to this diagrams are from top-only, bottom-only and top-bottom interference. Diagrams (b) and (c) show production in association with b quarks.

With the $\tan\beta$ enhancement, the decays of additional Higgs bosons to tau leptons and bottom quarks are most likely. Tau leptons are reconstructed more easily in the CMS detector than bottoms quarks and are much easier to separate from the large QCD multijet background produced from the high energy proton-proton collisions.

1.1.2 Vector Leptoquarks

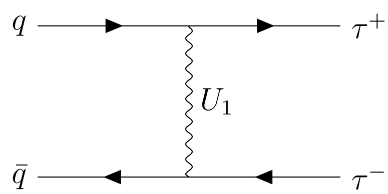
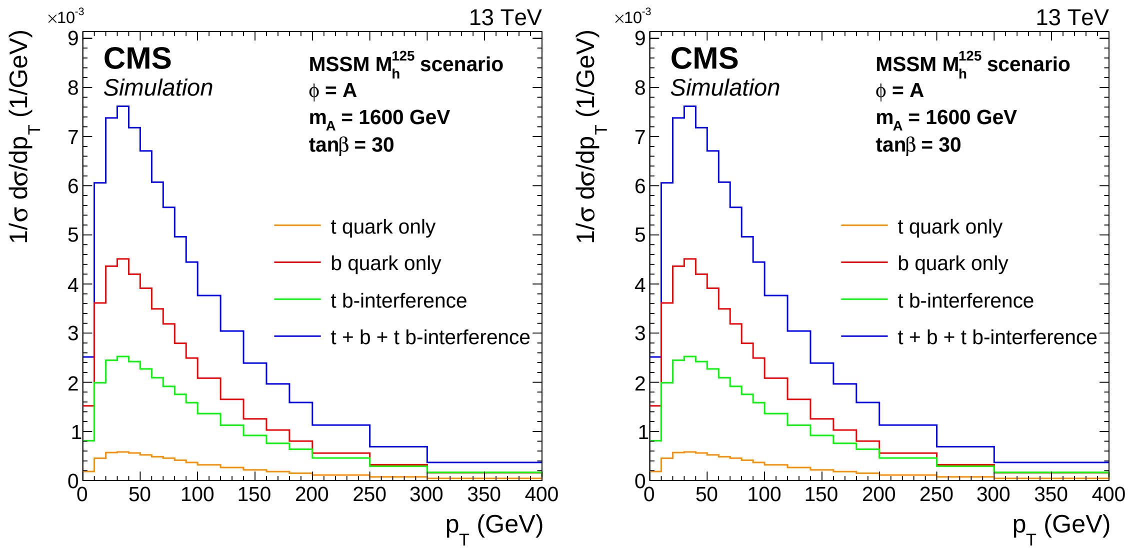


Figure 1.2: Feynman diagram showing the vector leptoquark t-channel interaction that produces a tau pair from a pair of bottom quarks.

1.2 Signal Modelling



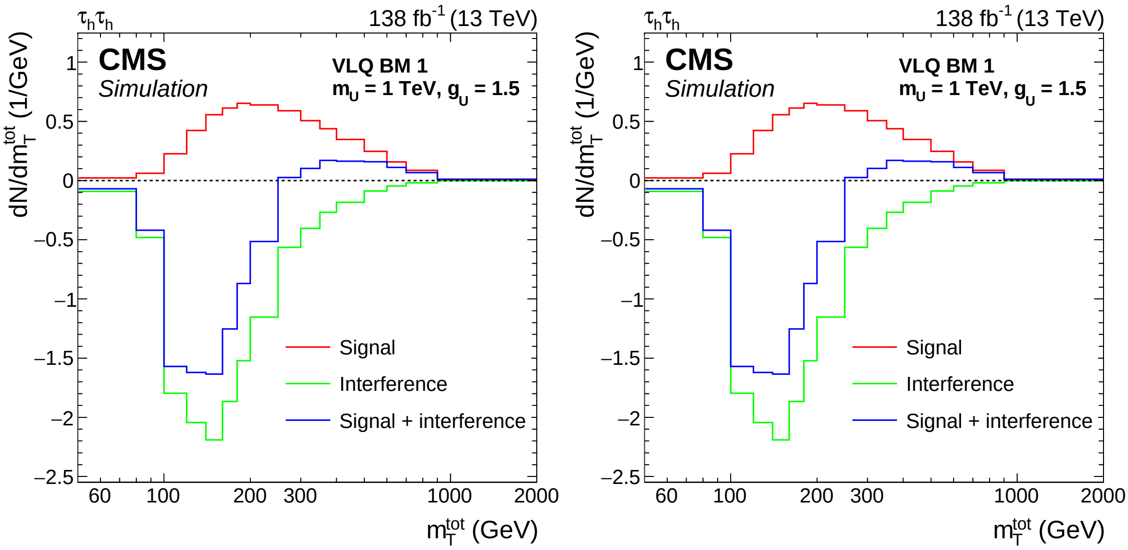
(a) (b)

Figure 1.3: MSSM signal.

1.3 Event Selection

Channel	Branching Fraction
$\tau_h\tau_h$	42.0%
$e\tau_h$	23.1%
$\mu\tau_h$	22.6%
$e\mu$	6.2%
ee	3.2%
$\mu\mu$	3.0%

Table 1.1



(a) (b)

Figure 1.4: VLQ signal.

1.4 Signal Extraction

1.5 Background Modelling

1.5.1 Overview

1.5.2 Embedding Method

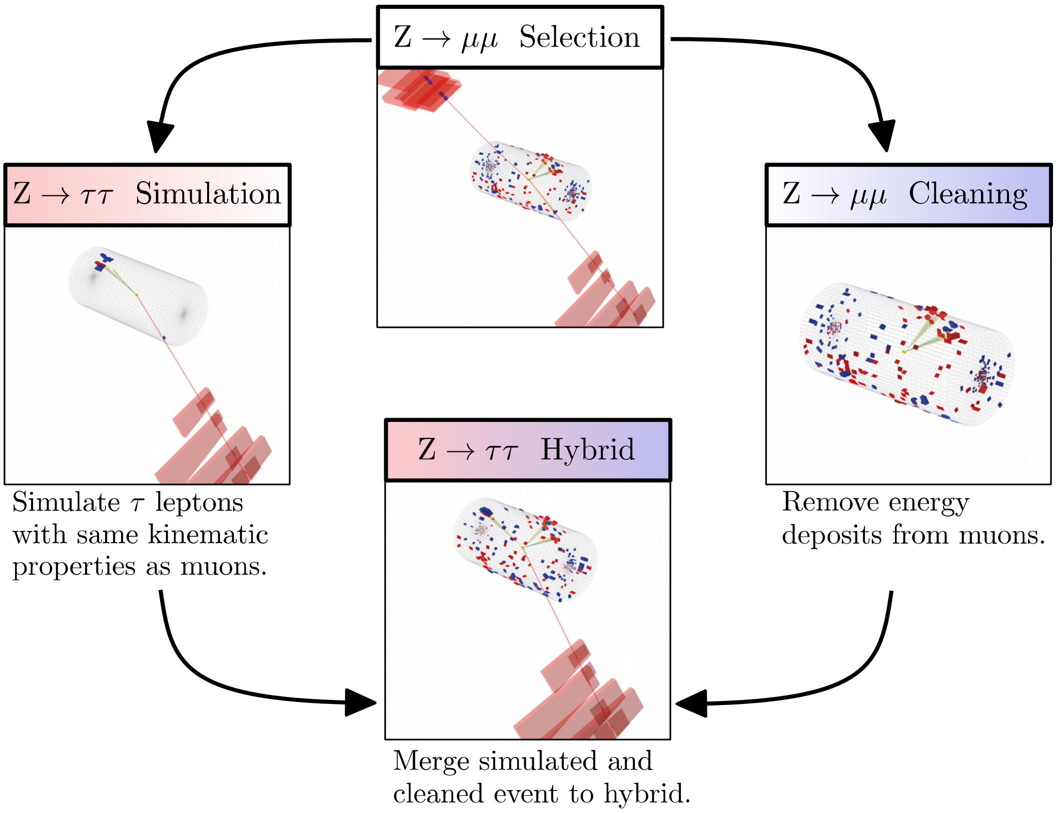
1.5.3 Fake Factor Method

1.6 Corrections

1.7 Results

1.7.1 Model Independent

1.7.2 Model Dependent



(a)

Figure 1.5: Embedding.

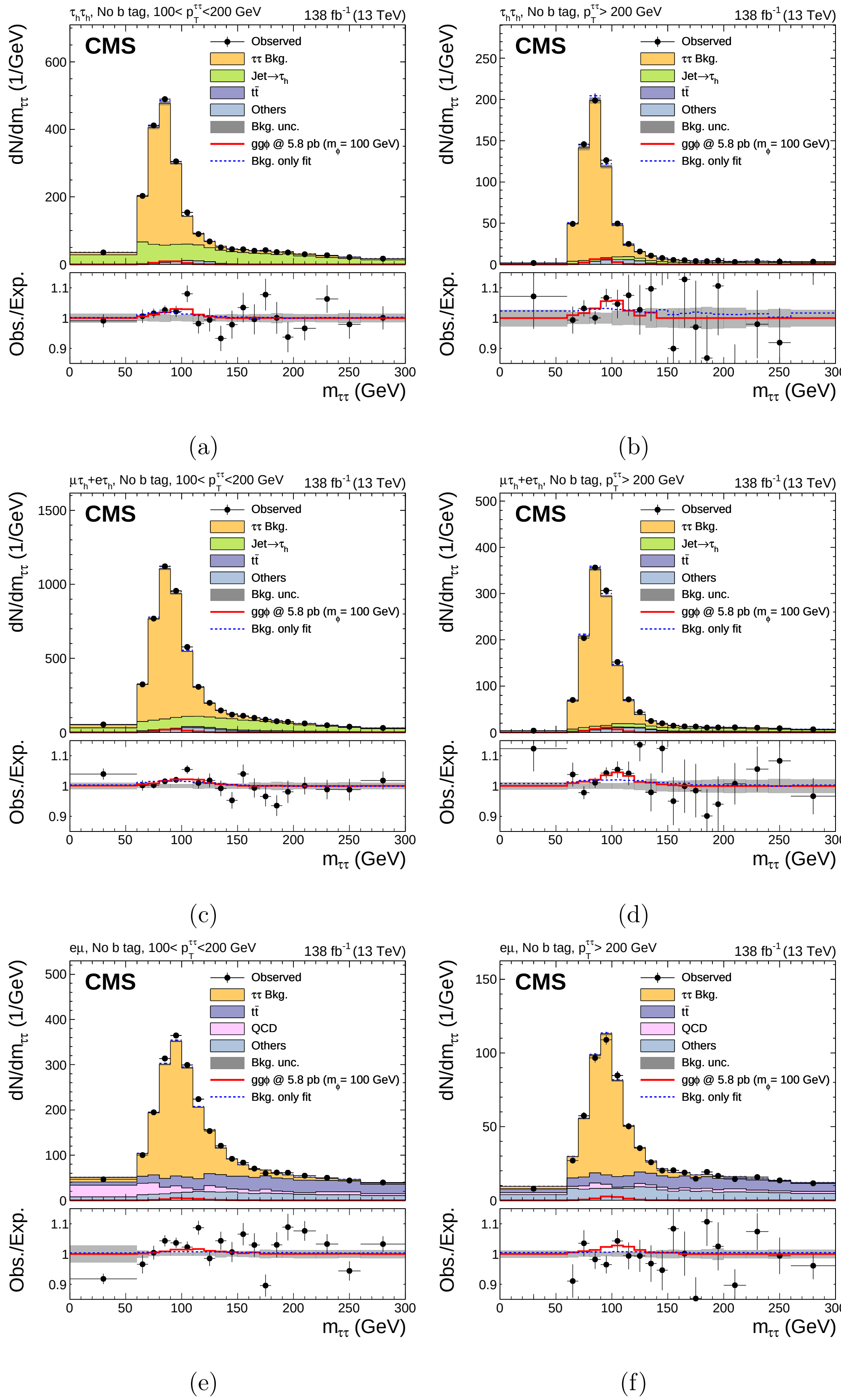
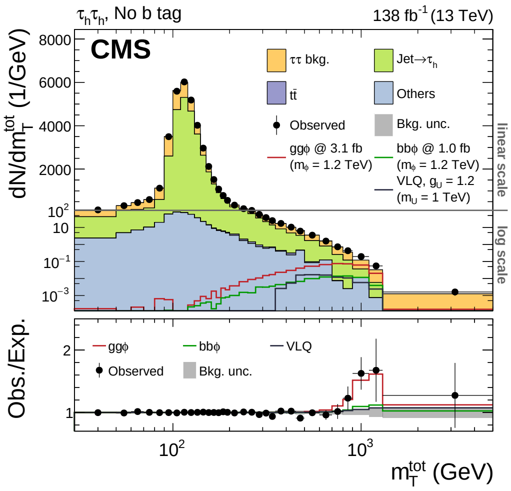
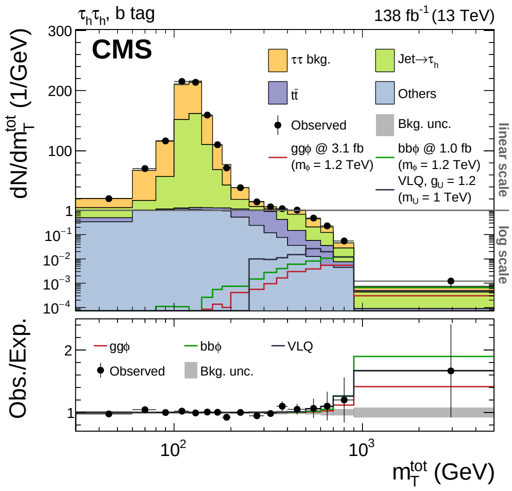


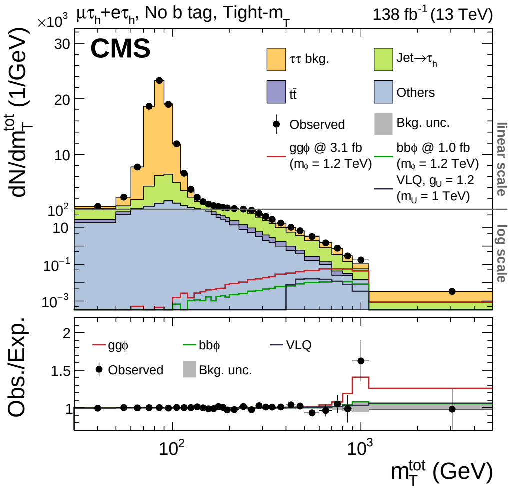
Figure 1.6: Low mass postfit.



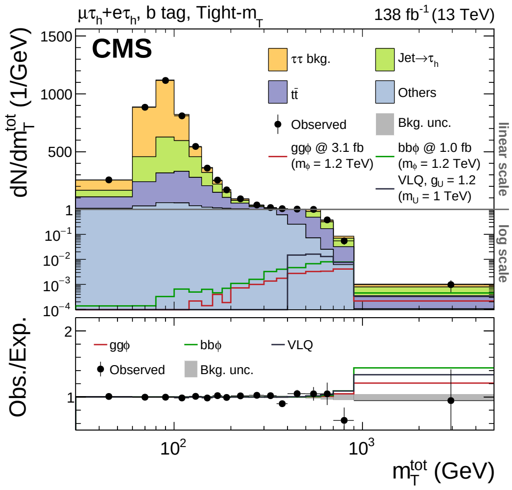
(a)



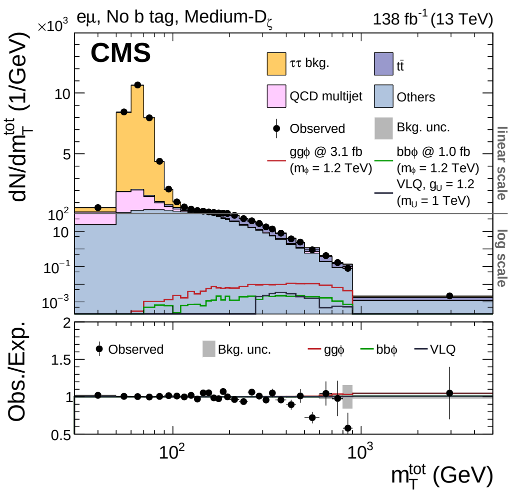
(b)



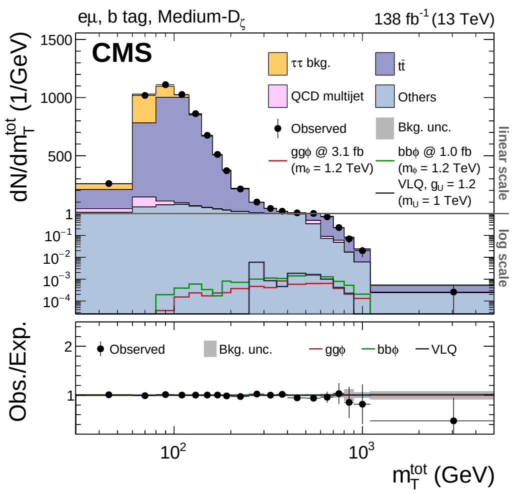
(c)



(d)

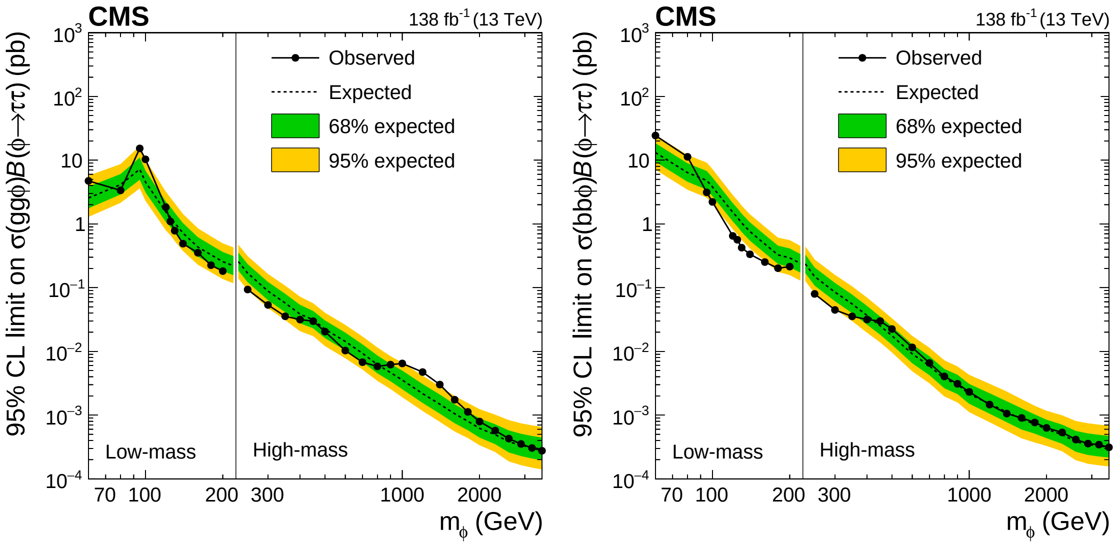


(e)



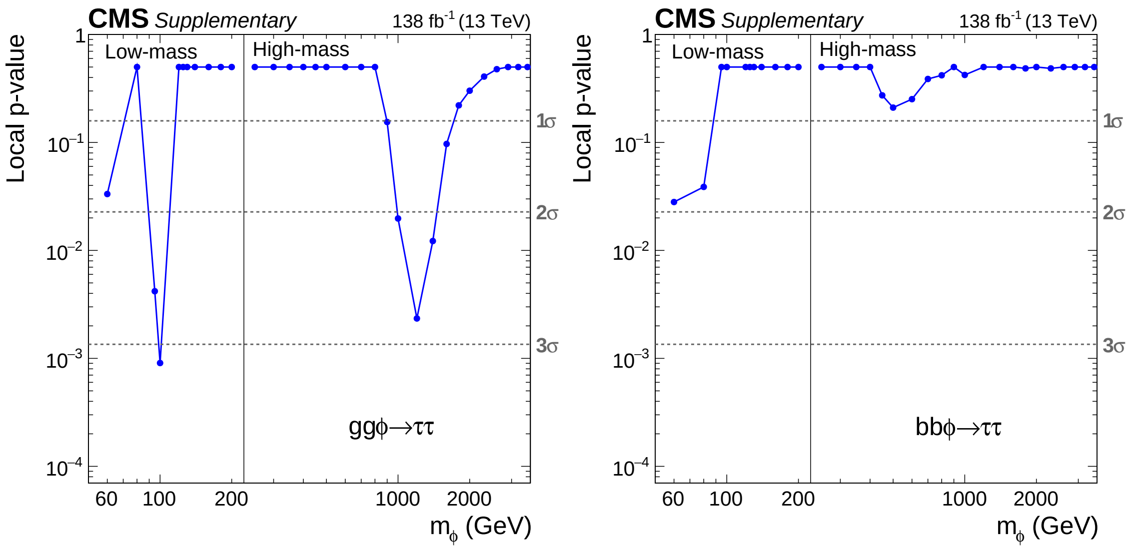
(f)

Figure 1.7: High mass postfit.



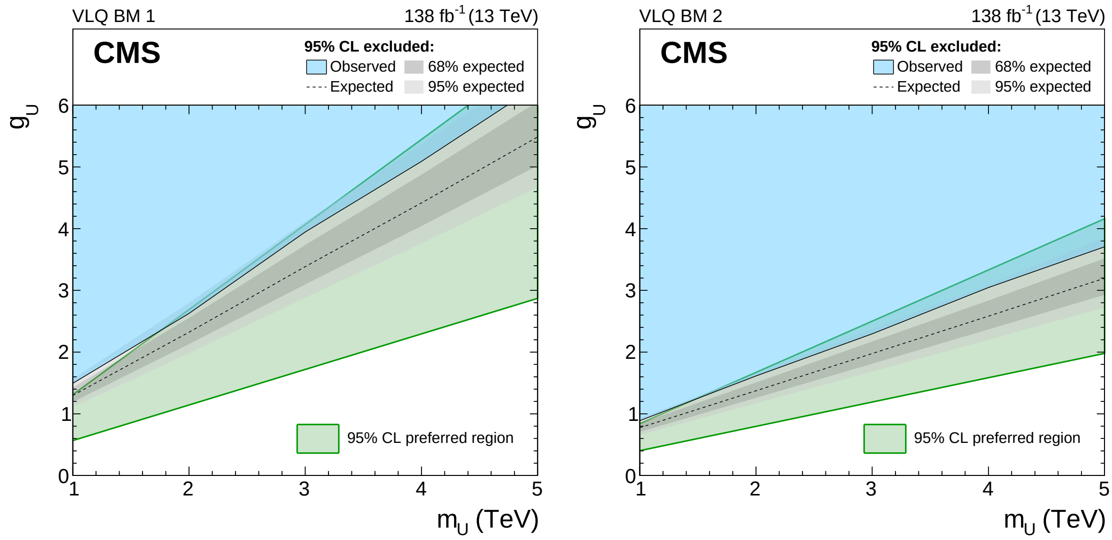
(a) (b)

Figure 1.8: Model independent limits.



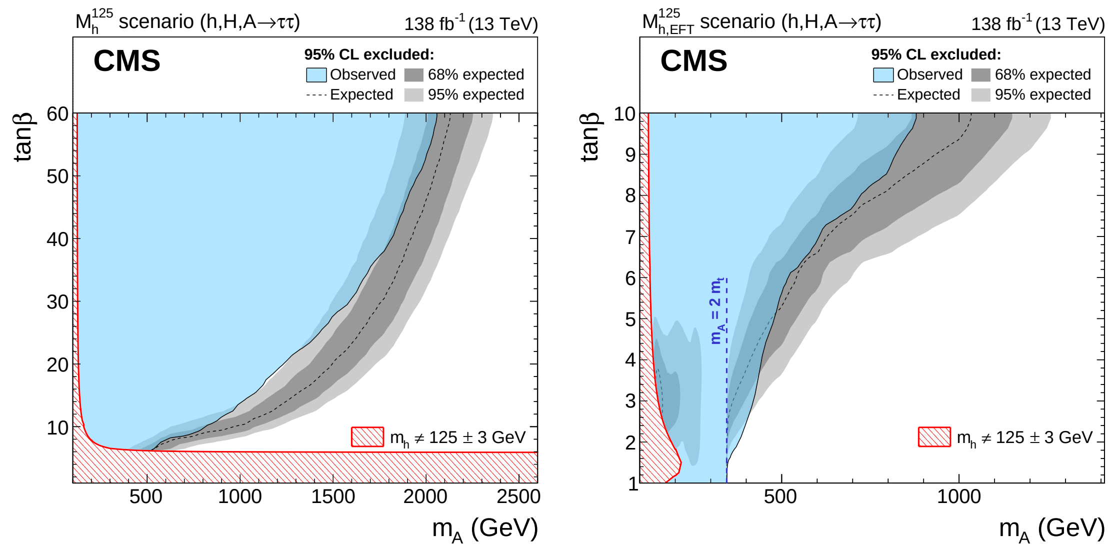
(a) (b)

Figure 1.9: Significance.



(a) (b)

Figure 1.10: VLQ limits.



(a) (b)

Figure 1.11: MSSM limits.